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Restoration By Design: Great Bay Estuary, New Hampshire

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RESTORATION BY DESIGN

Great Bay Estuary, New Hampshire

Final report prepared by The Nature Conservancy for the U.S. Department of Agriculture Natural Resources Conservation Services.

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Executive Summary

Oysters play a critical role in maintaining the health and resilience of an estuary, providing critical ecosystem services such as improving water quality and providing habitat. Historically, the Great Bay Estuary, New Hampshire was covered in healthy living oyster reefs. Due to historical overharvesting, disease and environmental stressors, oyster reefs have largely been lost resulting in a loss of these important ecosystem services. The Nature Conservancy and the University of New Hampshire have been working collaboratively since 2009 to conduct oyster reef restoration. In 2016, it was identified that further strategic restoration efforts including a near-term spatial plan were needed to enable a resilient and balanced ecosystem. The project funded by U.S. Department of Agriculture Natural Resources Conservation Services (NRCS) was called "Restoration by Design" and conducted from 2017-2020. The project included in water oyster reef restoration and assessment, that produced valuable information for the site selection criteria and identification of future sites. Stakeholder feedback was a critical component in building the plan and improving methodologies for future restoration. To develop a set of site suitability criteria and methodologies for "Restoration by Design", we conducted a synthesis and integration of historical and current data on spatial extent, condition and abundance at native oyster reefs, shell persistence, and oyster survival at restoration sites. We augmented our database with spatial layers from sediment maps, eelgrass distribution, shellfish management areas, and research results from oyster population dynamics. We then enhanced our criteria list with social interest layers, on permitting requirements and aquaculture lease areas to generate a comprehensive suite of site suitability criteria. This multifaceted approach of social and ecological considerations allowed us to best design and recommend sites and methodologies for future restoration. We recommend deploying multiple restoration methods within 24-53 acres across seven sites in the Great Bay Estuary System. We propose reef construction nearby native reefs with high density of reproductive adults, to provide substrate for natural recruitment. We suggest planting multiple year classes of oysters as stock enhancement on sites with existing cultch nearby degraded reefs to provide a density of oysters to ensure reproductive success. We advocate for temporary closure to recreational harvest at specific native reefs to allow for populations to rebound to a more normal state. We support and endeavor to experiment with coupled eelgrass and oyster restoration. We believe this multi-disciplinary and methodological approach will best advance the strategy of restoring oyster reefs and the ecosystem services they provide to the Great Bay Estuary. This report identifies best sites and methods for oyster restoration and describes a collaborative approach between restoration practitioners and oyster farmers. "Restoration by Design" will serve as a near-term strategy that lays the robust foundation for restoration and recovery of the Great Bay Estuary.

Acknowledgements

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Restoration by Design was developed through partnerships with academics and managers that have expertise in habitat restoration. The Piscataqua Region Estuaries Partnership (PREP) was a vital partner in facilitating and delivering on our stakeholder engagement process for the project. A steering committee comprised of members from The Nature Conservancy, PREP, NH Department of Environmental Services, NH Coastal Program, NH Fish & Game, Great Bay National Estuary Research Reserve (GB NERR), NH Sea Grant, and Natural Resources Conservation Service (NRCS) provided high-level guidance throughout the project. Academics from University of New Hampshire and staff from regulatory agencies provided critical and important technical assistance. Special thanks to Ray Grizzle, Krystin Ward, Tom Lippmann, Fred Short, Robert Atwood, Chris Nash, Chris Peter, Kalle Matso, Rachel Rouillard, Trevor Mattera, Don Keirstead, Steve Couture, Erik Chapman, Cory Riley. A massive thank you to our partners at the Jackson Estuarine Laboratory for use of the facilities and project support. A special note of appreciation to all the oyster growers of Little Bay, New Hampshire. Growers were engaged and provided valuable input, innovative ideas and feedback on restoration methodologies. Special thanks to Laura Brown, Brian Gennaco, Tim Henry and Krystin Ward for participating in restoration in 2019 and 2020. A shout of appreciation to Megan Latour of TNC for support with design and graphics. Through a truly collaborative effort and integration of knowledge the community provided invaluable support and guidance from project start to finish.

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I. Introduction

Purpose and Background

Oysters play a critical role in maintaining the health and resilience of an estuary. On average one adult oyster can filter up to 30 gallons of water per day, removing excess nutrients and suspended particles. Oyster reefs provide important habitat for native fish and invertebrates. Historically, the Great Bay Estuary (GBE), New Hampshire was covered in healthy living oyster reefs. Due to historical overharvesting, disease and environmental stressors, oyster reefs in GBE have largely been lost resulting in a loss of the important ecosystem services oysters provide. As part of the Great Bay 2020 Initiative, The Nature Conservancy (TNC) identified oyster reef restoration as an essential strategy for improving the conditions in GBE. TNC currently has restored within a 28.5-acre footprint through a collaborative partnership with the University of New Hampshire (UNH). However, further strategic restoration efforts are needed to enable a resilient and balanced ecosystem.

The need for a spatially explicit restoration strategy resulted in the project "Restoration by Design" that was conducted from 2017-2020. The plan developed a restoration strategy for GBE to include a review of historic and current restoration sites results integrated with current bathymetric surveys to understand sediment dynamics to build a physical, ecological and human-interest site suitability model in 2018 and 2019. The process was largely driven by stakeholder input, facilitated by staff of the Piscataqua Estuaries Resource Partnership (PREP). This strategy will serve as a near-term master plan for oyster restoration opportunities in the system, and aims to integrate and balance site suitability for oyster restoration with recreational harvest areas, oyster aquaculture opportunities, and eelgrass regeneration areas recognizing that these habitats and activities must all be allowed to coexist in order to promote a healthy ecosystem with vibrant local marine-based heritage and economy. Restoration by Design identified best sites and methods for oyster restoration and describes a collaborative approach between restoration practitioners and oyster farmers.

The project included oyster reef restoration implementation and assessment, with the intention of making progress toward long-term restoration goals, further developing our body of in-the-water restoration experience and continuing to refine our collective understanding of best site selection, design, and implementation practices. We conducted bathymetric mapping on the restoration sites to further understand sediment dynamic effects on restored sites and included the results in our site selection criteria. TNC in partnership with PREP worked with key stakeholders to solicit comments on the restoration plan and adjusted the plan as needed to accommodate concerns or conflicts. A combination of in-water science and stakeholder feedback enabled the successful production of this plan; spatially explicit maps and improved methodologies for future reef construction. Our goal is that Restoration by Design will enable TNC and our Great Bay habitat restoration and resource management partners to map out and pursue a collective vision for oyster restoration efforts whilst considering other important habitats.

Great Bay Study Area

Great Bay (GBE) Estuary is a tidal estuary with over 150 miles of shoreline. It consists of three main parts: Great Bay, Little Bay, and the Piscataqua River which feeds into the Atlantic Ocean. The bay encompasses over 6,000 acres (24 km^2), not including its several tidal river tributaries. Seven tributaries feed into GBE from 1,000 sq miles of New Hampshire and Maine watershed connecting this entire region to the Gulf of Maine (Odell et al., 2006). GBE contains many important habitats including eelgrass beds, salt marsh, and oyster reefs that provide a number of benefits and ecosystem services to people and wildlife. Great Bay Estuary has been identified by federal and state agencies as a priority area for these important habitats and species supported within and was designated as a National Estuarine Research Reserve in 1989. The habitats within GBE support federally endangered and threatened species, provide nursery grounds for species managed under the Mangnuson-Steveson Fishery Conservation and Management Act (MSA), and provide critical habitat for diadromous fish.

GBE was renowned for its plentiful resources when first colonized in the early 1600's (lumber, fisheries, shellfish, ore, etc.) when it had previously only been inhabited by local Native American tribes (Short, 1992). As a result of these booming industries in the early 1600's-1900's pollution, sedimentation, over harvesting, increased human population and development, and habitat destruction/degradation caused significant negative impacts on the estuary (Short, 1992). Between 1988 and 2012 the GBE experienced increased nitrogen loading from Waste-Water Treatment Facilities (WWTF) and non-point sources, far exceeding the threshold of 14 tons per square mile for eelgrass health (PREP, 2018; Latimer and Rego 2010). Improved regulations for WWTF have reduced the amount of nitrogen loading, but the levels are still high enough to be considered a detriment to the environment (PREP, 2018). Improved management of GBE and its resources have made significant improvements across the estuary; however, GBE is still experiencing poor water clarity, an increase in impervious surfaces and associated non-point pollution, declining eelgrass beds and low oyster populations (PREP, 2018).

Historically, GBE contained many acres of living and thriving eastern (*Crassostrea virginica*) oyster reefs; oysters were so plentiful in the 1600's anecdotal evidence suggests they were used to feed livestock (Short, 1992). Due to the above-mentioned problems: pollution, historical overharvesting, and disease inflicted from two parasitic organisms, Dermo (*Parkinsus marinus*) and MSX (*Haplosporisium nelson*) we have seen over a 90% decrease in our oyster reefs today resulting in only little over 100 acres (PREP, 2018). We currently have 6 major native oyster beds within the Great Bay system (Figure 1) that were last mapped in 2013 to assess oyster population spatial extent and density and updated in 2020. In 2013, there was a reported 120 acres of reef mapped (Grizzle &

Ward, 2013). As part of Restoration by Design, native beds were surveyed, and maps were updated in 2020. Commercial harvesting of wild oysters has been reduced to a half bushel only for recreational harvesting to protect GBE's wild reefs. With this decrease in oyster reefs over time we have seen the associated loss of the ecosystem services that are much needed for the GBE (Coen et al., 2007, Grabowski et al., 2012). In 2009, The Nature Conservancy in partnership with Dr. Grizzle and Ms. Ward of the Jackson Estuarine Laboratory (JEL) University of New Hampshire started restoring oyster reefs within Great Bay in large part to replenish the ecosystem services provided by a network of oyster reefs.

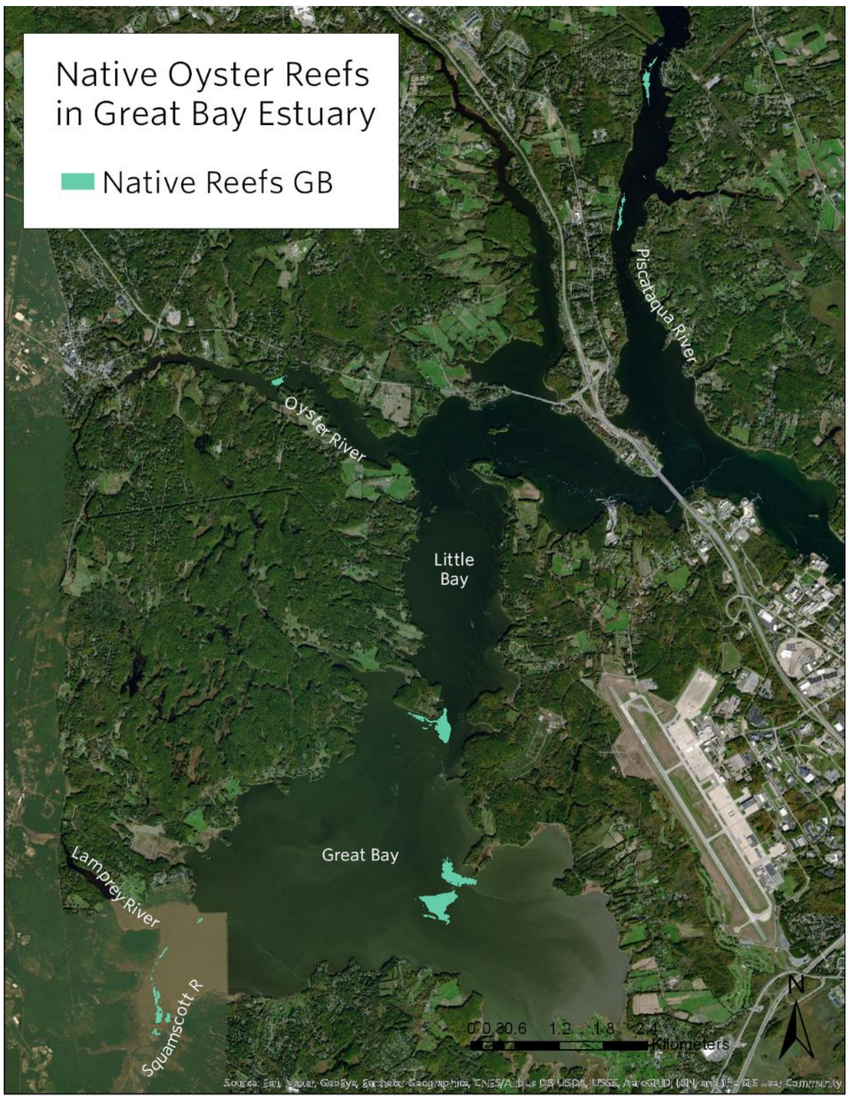


Figure 1. Updated map of the Great Bay Estuary with the seven native oyster reefs (Lamprey, Squamscott, Nannie Island, Woodman Point, Adams Point, Oyster, and Piscataqua) in turquoise. Mapping completed in 2020.

Making the Case for Oyster Reef Restoration

As ecosystem engineers, oysters and the reefs they form provide ecosystem services through physical structures and biological processes. Some valuable ecosystem services provided by oysters within the Great Bay system include creating habitat for various life history stages of native fish and invertebrates, removing excess nutrients from the water column through filtration, improving water clarity, removing nitrogen through tissue assimilation and denitrification on reef materials and in surrounding sediments, stabilizing sediment, sequestering carbon and buffering against ocean acidification (Grabowski and Peterson, 2007, Coen et al., 2007, Piehler and Smyth, 2011, zu Ermgassen et al., 2013a, zu Ermgassen et al., 2013). These services are also expressed as benefits to people such as an increase in recreational fishing due to increase in fish and invertebrate species associated with the reef, and progress towards mandated total maximum nitrogen loads through the tons of nitrogen removed through tissue assimilation or denitrification (Higgins et al. 2011; Rose et al. 2014; Bricker et al. 2020). Two main ecosystem services drive the focus of our restoration work in the Great Bay Estuary (Figure 2).

Figure 2. The Nature Conservancy in New Hampshire's ecological goals for oyster restoration: improving water quality through filtration, and habitat provisioning for fish and invertebrates by rebuilding important oyster reef habitat.

Improving Water Quality

We aim to improve water quality by taking a two-pronged approach, improving water clarity and removing excess Nitrogen in GBE. Oysters are filter feeding bivalves and contain hairs (cilia) inside their gills that beat and collect or pull particles from outside of the water column (Zu Ermgassed et al., 2016). These particles can include algae, diatoms, and detritus. Through the filter feeding process oysters remove particles from the estuary and convert them into feces or pseudofeces (Figure 3). One adult eastern oyster (*Crassostrea virginica)* can filter on average 30 gallons of water in one day. The rate of filtration is most affected by the size of the oyster, water temperature, sediment load, and salinity (Zu Ermgassen et al., 2016). The Nature Conservancy developed an oyster calculator to calculate filtration rate based on key information about the populations of oysters in the system (https://oceanwealth.org/tools/oyster-calculator/). The calculator can be used to determine population level filtration and full-estuary level filtration, thus, informing future restoration efforts where water quality improvement is a restoration goal.

It was estimated that GBE contained over 1,000 acres of eastern oyster (*Crassostrea virginica)* reef in the 1970's, which could filter the entire estuary in just 4 days (Bolster, 2002). By 2000 that number has been reduced by 90%, resulting in a little over 100 acres of oyster reef. As a result, the filtration rate of the eastern oyster populations in GBE has significantly decreased lengthening the amount of time required for full-estuary level filtration. Mapping conducted in 2009 concluded 87ha of oyster reef in Great Bay (Grizzle and Brodeur, 2004; Grizzle and Ward, 2009). This results in a filtration rate of 4.43 x 10^8 liters per hour (Zu Ermgassen et al., 2016). GB contains between 40-60 billion gallons of water (depending on the tide) with a residence time of 5-20 days (Bilgili et al., 2005; https://www3.epa.gov/region1/npdes/schillerstation/pdfs/AR-186.pdf).

Figure 3. Two tanks containing Great Bay estuary water at an outreach event showing the results of live oysters filter feeding over the course of an hour. Tank on the right contains live oysters, while the tank on the left does not.

Nitrogen Removal

Whilst oysters filter feed, they are also removing nitrogen from the estuary through this filtration and subsequent ingesting particles. The oyster will assimilate the nitrogen into their shells and tissues as they grow and by enhancing denitrification (the microbial driven process of bioavailable nitrogen transformation to di-nitrogen gas) (Rose et al. 2014; Bricker et al. 2020). Waste produced by oysters enriches the sediments on the seafloor around the reef, increasing the amount of nitrogen and changing the microbial community (Richardson et al., 2008). The addition of waste materials can increase rates of denitrification (Newell, 2004, Newell et al., 2005). Denitrification is a microbial-driven process of converting bioavailable or reactive nitrogen to non-reactive di-nitrogen (N_2) gas, which removes the nitrogen from the water column and the ecosystem. The amount of nitrogen removal from denitrification in the Great Bay system depends on the shape and vertical structure of the reef and biomass of the oysters (Caffrey et al., 2016; Carmichael et al., 2012). Increasing the quantity of size/biomass of oysters on the reefs through restoration will increase the amount of nitrogen removed though assimilation and denitrification. Oyster restoration may compliment land-based management approaches for nitrogen reduction (Rose et al., 2013) and is currently being considered for inclusion in the Chesapeake Bay (Reichert-Nguyen, 2018).

Habitat Provision

Oyster reefs provide structural habitat for fish and invertebrates, with a loss of these reefs we've also lost that important habitat. Eastern oyster larvae prefer to settle and grow on top of other oyster shells. As a result, oysters create large vertical complex reef structures with small interstitial spaces and diversify the seascape bottom. These spaces provide important habitat for a variety of juvenile fish and invertebrates and enhance fish production by providing refuge from predation, increasing food availability, and providing substrate for recruitment and settlement (Grabowski et al. 2005). Studies have quantified this value of habitat provisioning in a variety of locations (Lenihan & Peterson, 1998; Harding & Mann, 1999; Grabowski et al., 2012; Zu Ermgasson et al., 2015). In the Great Bay Estuary, preliminary sampling has shown a variety of species utilizing the reefs including species of conservation concern such as American Eel, *Anguilla rostrate* (personal communication, GBNERR). We will continue sampling around the native and restored reefs to better quantify the value of habitat provisioning that oyster reefs provide in the Great Bay Estuary and whether these values change based on native vs restored reefs.

Oysters aren't the only ecosystem engineer impacting water quality and providing habitat for ecologically and economically important species in the GBE. Eelgrass (*Zostera Marina L.)* beds also pull nutrients out of the system, filter, and recycle those nutrients (nitrogen and phosphorous) into their roots and blades improving water clarity. In addition, Eelgrass beds stabilize sediment, sequester carbon and buffer waters against ocean acidification (Burdick et al., 2020). However, there has been significant loss of eelgrass beds with the current standing stock of eelgrass, 60% of what they were in the 1980s and 1990s (Short 2012; PREP, 2018; Burdick et al. 2020). We utilize oyster restoration as a tool to improve water quality in the estuary and by doing so reduce stress and assist in the potential success of eelgrass recovery.

Restoration History

The Nature Conservancy has been working collaboratively to restore oyster reefs and their ecosystem function to GBE since 2009 in collaboration with University of New Hampshire. Since initiation, we have restored oyster reefs within a permitted 28-acre footprint in the GBE. Throughout this process we have deployed adaptive management strategies based on monitoring and research to improve our restoration techniques. Initially, restoration efforts were small spatially and have grown over time as illustrated in Table 1 and Figure 4. Site location was chosen based on permittable area, suitable substrate for depositing reef base, lack of eelgrass presence/potential, and later based on local research relative proximity to a healthy natural reef to increase the probability of natural recruitment to the restoration reef (Eckert, 2016, Atwood & Grizzle, 2020).

Restoration efforts have historically involved two major steps: construction of a hard substrate reef base followed by deployment of remotely set oyster spat-on-shell (SOS) onto the constructed reef base. These methods are common in systems that are substrate and recruitment limited (Brumbaugh & Coen 2009). Hard substrate deployed in New Hampshire is composed of primarily seasoned surf clam shell (*Spisula solidissima*) shipped in from M&W livestock in Rhode Island. It is supplemented with oyster shell from a shell recycling program with the NH Coastal Conservation Association. The shell is deployed on the bottom as a substrate foundation adjacent to native reefs to recruit wild spat settlement from native populations. It has long been thought that placing substrate nearby native reefs increases natural recruitment. In 2016, Eckert found in a localized study of Great Bay native and restored reefs that there was significantly more recruitment on "restoration reefs less than 1 km from a native reef compared to restoration reefs greater than 1 km from a native reef" (Eckert, 2016, Atwood & Grizzle, 2020). The amount of shell deposited differed by year depending on site and the availability of resources (Table 1).

The method of shell distribution has varied and evolved over time. For projects constructed between 2009-2015 the "shell was deliberately distributed unevenly to result in several heavily "shelled" areas within the overall restoration area footprint" (Grizzle & Ward 2016). In 2015, an assessment of nine restoration sites was conducted to determine the status of the restoration events and help refine future restoration methodologies (Grizzle and Ward, 2016). Methods included measurement of reef shape, reef size, reef height, oyster density, and oyster size-frequency distribution as suggested by Baggett et al (2015). Results showed that most sites had experienced substantial losses of shell cover since initial construction, with only 20-60% cover present and that shell layers had become buried by fine sediments (sedimentation) (Grizzle & Ward, 2016) (Table 1).

Recent studies and local monitoring have found that reef geometry, specifically height is a driving factor in restoration success (Schulte et al. 2009, Lipcius et al. 2015, Grizzle & Ward 2016, Colden et al, 2017). Colden et al (2017) found that reefs in the Chesapeake lower than 0.3 m experienced sedimentation and were eventually buried. Given the recent findings and how reef height was greatly impacting restoration success, we adapted our strategy. Starting in 2016, shell has been deployed in a pattern of many small piles with a vertical height of 0.3-0.5m above the seabed so that the reef edge is maximized for natural spat settlement and avoids heavy sedimentation (Section II: In water restoration).

Constructed reef areas of shell piles are amended to supplement recruitment with laboratory-raised and volunteer-grown “spat-on-shell” from remotely set larvae. TNC contracts with Dr. Grizzle and Ms. Ward at the University of New Hampshire’s Jackson Estuarine Laboratory (JEL) to rear oysters or spat on shell (SOS) at the laboratory for “seeding” the constructed shell base (see section III for detailed methods). Number of larvae obtained from the hatchery, and subsequent settling and grow out success varied year to year depending on resources for larval purchase and environmental conditions for success (Table 2). SOS were also provided by volunteers participating in the Oyster Conservationist Program.

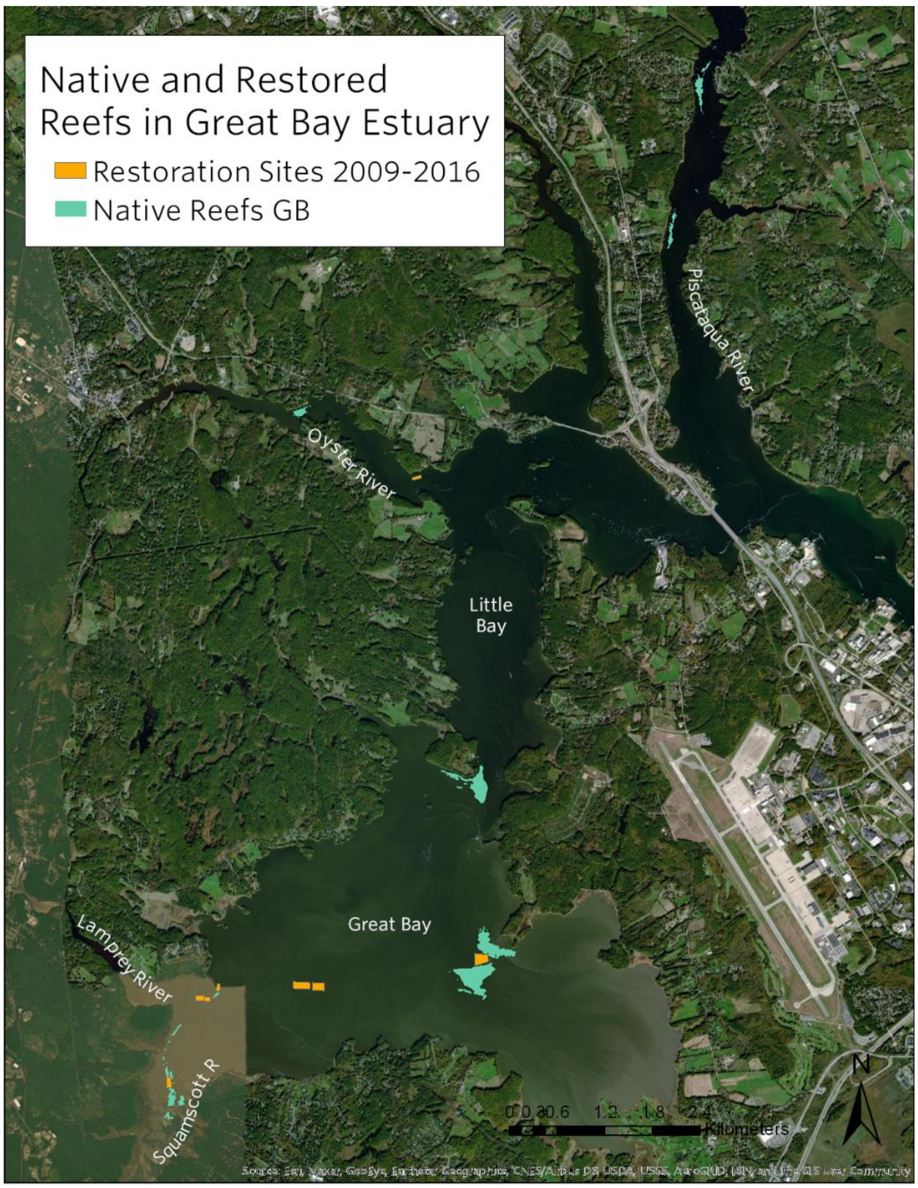


Figure 4. Historical TNC restoration sites (orange) (completed from 2009-2016). Native oyster reefs (turquoise) in Great Bay from mapping conducted by Ray Grizzle and Krystin Ward in 2020 (Piscataqua oyster reef was mapped in 2013).

Table 1: Summary data on shell base characteristics 2009-2016 (Grizzle & Ward, 2016).

Year	Reef Name	Restoration area (Ac)	Volume of Shell (yd#)	Initial Shell cover (% of area)	2015 Shell Cover (% of area)
2009	Oyster River #1	0.2	30	20%	9%
2010	Oyster River #2	1.0	100	(nd)	7%
2011	Lamprey River #1	2.0	200	60%	3%
2011	Lamprey River #2	1.0	100	20%	26%
2012	Squamscott River	2.0	83	20%	5%
2013	Lamprey River #3	2.0	200	38%	25%
2013	Piscataqua River	1.5	150	54%	23%
2014	Great Bay #1	2.5	250	25%	1%
2015	Great Bay #2	2.5	250	21%	4%
2016	Nannie Inner	5	500	N/A	N/A

Table 2. Summary data on raised SOS at the UNH-JEL from 2009-2016 (personal communication, Grizzle & Ward)

Year	# Larvae purchased	Settling success (SOS)	# Oysters Deployed	Location of deployment
2009	N/A	N/A	3000	Oyster River 1
2010	3 million	~6%, 201,000	201K (UNH), 3K (OC)	Oyster River 2
2011	6 million	~7.8%, 472,000	335K (UNH), 17K (OC)	Lamprey 1 and 2
2012	2.5 million	23%, 580,000	85K (UNH), 11K (OC)	Squamscott River
2013	10 million	~31%, 3.1 million	629K (UNH), 58K (OC)	Lamprey 3 and Piscataqua
2014	10 million	N/A	226K (UNH), 7K (OC) *approximate numbers	Great Bay 1
2015	N/A	N/A	316K (UNH and OC)	Great Bay 2
2016	12 million	38%, 4.6 million	660K (UNH), 35741K (OC)	Nannie Island Inner

Oyster Conservationist Program

The Oyster Conservationist (OC) Program is an important community engagement component of oyster restoration in Great Bay. An Oyster Conservationist (OC) is a community member in the coastal area of New Hampshire who advocates or acts for the protection and preservation of the environment and wildlife. Participants in the OC

Program work towards improving the health of Great Bay by raising oyster SOS for TNC's oyster reef restoration projects. Volunteers adopt a cage with SOS for an eight-week period cleaning and caring for the cage while also collecting data throughout the summer on survival, growth, invasive species, and wild oyster spat settlement. The program has grown from just 14 sites in 2006 to 80+ sites in 2019. Spatially these sites are located across Great Bay, Little Bay, Piscataqua River, coastal NH, and its seven tributaries (Figure 5). The data collected provides information on conditions to inform future oyster restoration efforts in Great Bay Estuary. As a citizen science community engagement program, a major goal of the OC Program is to create environmental stewards that advocate or act for the protection and preservation of the environment and wildlife. As a result of the OC Program, almost 250,000 oysters have been placed into Great Bay to begin contributing those important ecosystem services to people and wildlife since 2006 (Table 3). The important benefits that the OC Program provides to Great Bay (community engagement, oyster production for reef restoration, and data collection) makes this program a valuable contribution to the Great Bay estuarine ecosystem.

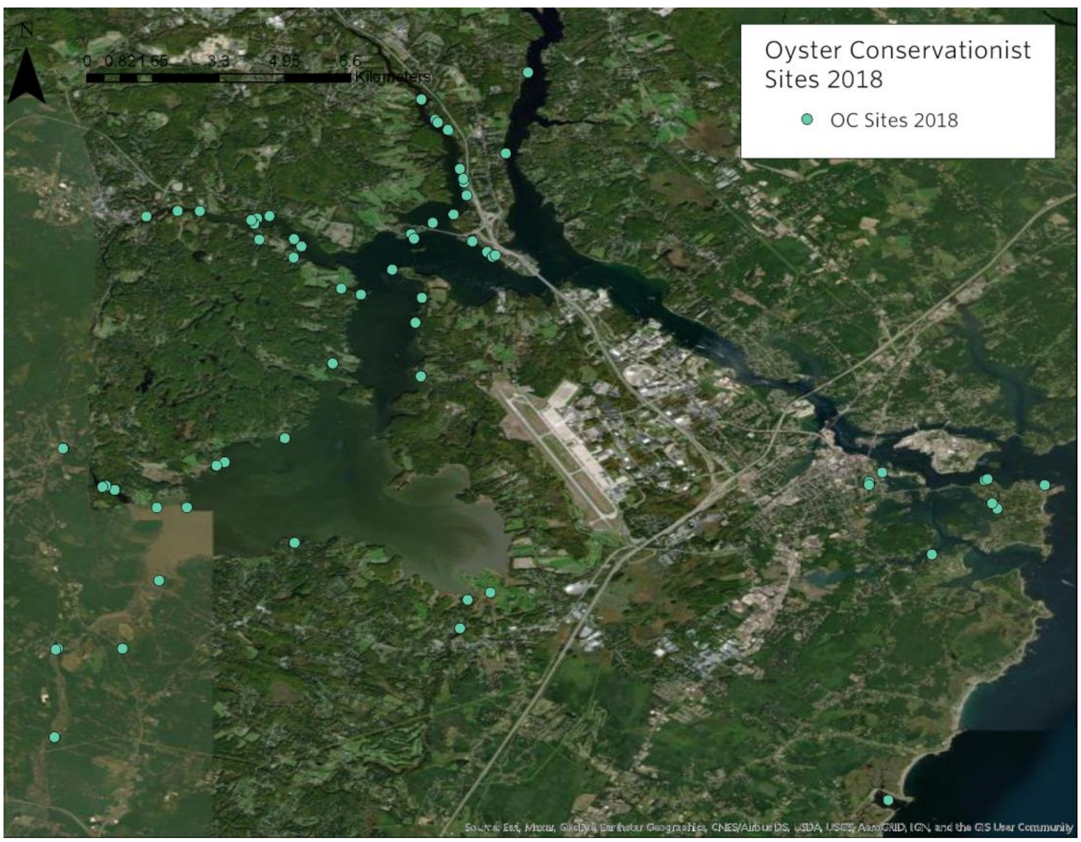


Figure 5. Oyster Conservationist sites in 2018. Only includes sites in NH and not the ME program which ended in 2019.

Table 3. Data from TNC's Oyster Conservationist seasons 2006-2018.

Year	# of OC sites	# Oysters Raised	# Oysters Cumulative
2006	14	9,362	9,362
2007	16	5,343	14,705
2008	17	3,825	18,530
2009	24	3,028	21,558
2010	30	3,066	24,624
2011	41	17,303	41,927
2012	50	11,046	52,973
2013	68	57,927	110,900
2014	94	7,542	118,442
2015	85	5,800	124,242
2016	85	35,741	159,983
2017	89	38,515	198,498
2018	89	22,482	220,980

The OC Program had sites in Maine (~10 sites) from 2014-2018. These volunteers received oysters to care for and collect data on over the course of 8-10 weeks. Oysters were then deployed separately onto a wild oyster reef in Maine waters. This program was discontinued in 2019 because of logistical problems including permitting and the deployment of the oysters (oysters grown in ME are not allowed to be deployed in NH waters).

II. In Water Restoration (2017 and 2018)

Overview

The Nature Conservancy in collaboration with Dr. Grizzle and Ms. Ward of UNH JEL restored within 10.5 acres across three areas in the summer of 2017 & 2018. Restoration events included four main methods (1) Reef construction (2) Oyster spat on shell production (3) Visual and biological sampling to determine shell cover and SOS oyster survival, growth, natural recruitment and (4) Bathymetric surveys to examine sediment dynamics at the restoration sites. Restoration was conducted within a 5-acre footprint at Nannie Island in 2017, adjacent to the 2016 restoration site. In 2018, there were two general project areas, one west of Woodman Point in a 2.5-acre site in Newington and a second site consisting of 2 areas (1 and 2 acres at the mouth of the Lamprey River) in the Town of Newmarket (Figure 6). All restoration sites were chosen based on their proximity to natural oyster reefs (Eckert 2016). In addition, these sites had not been covered in eelgrass since 2011 (PREP, 2018).

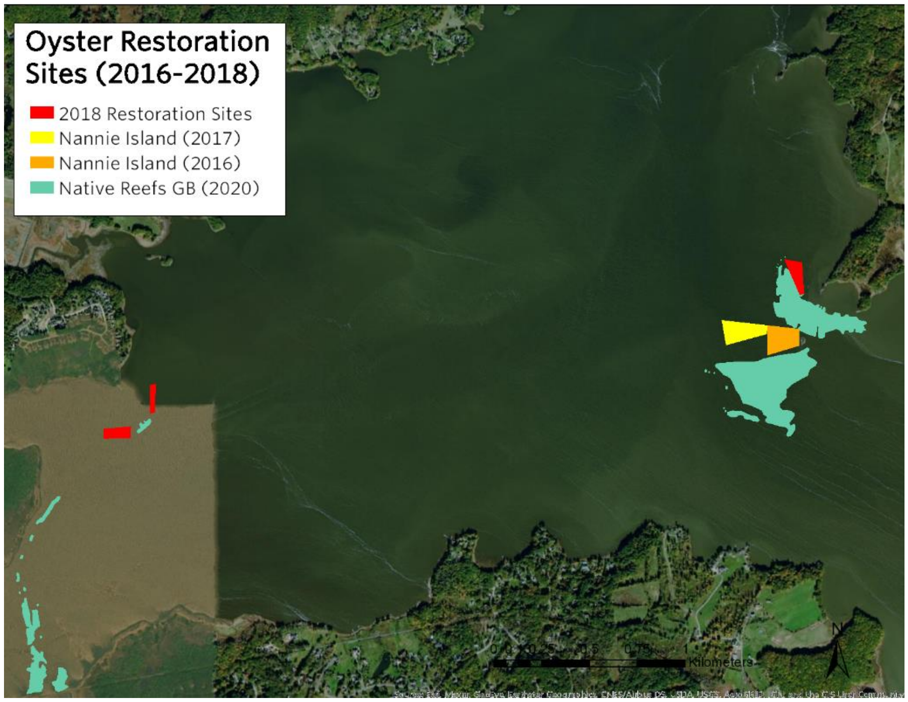


Figure 6. Oyster restoration projects completed from 2016-2018 (red, orange, and yellow) compared to the nearby native oyster reefs (turquoise). Shown by the figure, restoration projects were placed near a native oyster reef based on previous research.

Wetland permits for all sites to authorize the construction of the reef were applied for and granted from NH DES for the specific restoration season. NHDES Wetlands Bureau permit #2017-01103 that expires on June 6, 2022 was issued on June 14, 2017. The Nature Conservancy (TNC) is named as a collaborator in the permit application narrative, along with the Natural Resources Conservation Service (NRCS) as the funding agency. NHDES Wetlands Bureau permit #2018-01426 01103 was issued on June 18, 2018 with an expiration date of June 18, 2023. TNC and the University of New Hampshire (UNH) are named as collaborators in the permit narrative. Scientific permits authorizing the deployment of spat on shell and sampling of oysters were granted from NH F&G. Permit No. MFD 1726 was issued by the NH Fish and Game Department to the applicant (Raymond E. Grizzle) on March 9, 2017. Permit No. MFD 1814 was issued by the NH Fish and Game Department to the applicant (Raymond E. Grizzle) on February 8, 2018.

Reef Construction

Nannie Island:

The 5-acre site was designed to be juxtaposed with the native oyster reef at Nannie Island and the 2016 restoration site (Figure 7). Prior to shell placement the site was surveyed on June 16 and 21, 2017 with underwater video to characterize bottom conditions and confirm no eelgrass was present at the site. Additionally, Dr. Lippmann of UNH CCOM provided high-resolution bathymetry data from a sonar survey of the site (section bathymetric mapping). The video classification was overlaid on the bathymetric data to produce pre-construction maps. These two methods combined enabled a best-case scenario shell design plan for the site. Shell was designed to be deployed in piles on the inner portion of the restoration site, absent in the middle deep section and in a thin layer on the western shoal (Figure 8). 500 cubic yards of seasoned clam shell from M&W livestock was transported to Granite State Minerals in Portsmouth, NH where the shell was loaded onto a Riverside and Pickering Barge. The shell design maps were given to the barge operator of Riverside and Pickering and the shell was deployed in 12 individual mounds and a lightly shelled area at the site on June 27-28, 2017 (Figure 9).

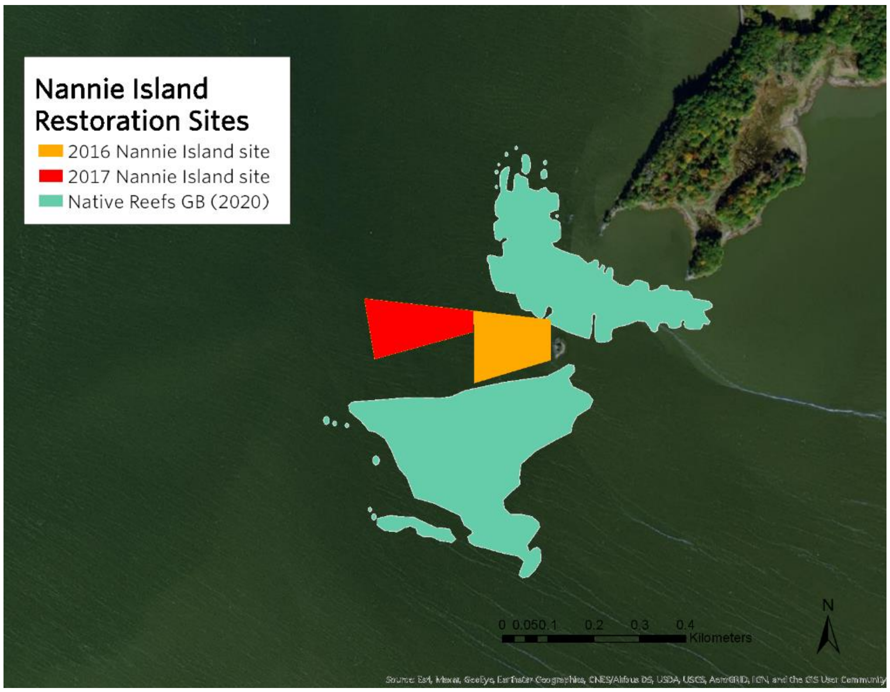


Figure 7. Close up of the Nannie Island 2016 and 2017 restoration sites (red and orange) compared to the native Woodman Point (upper) and Nannie Island reefs (lower) (turquoise).

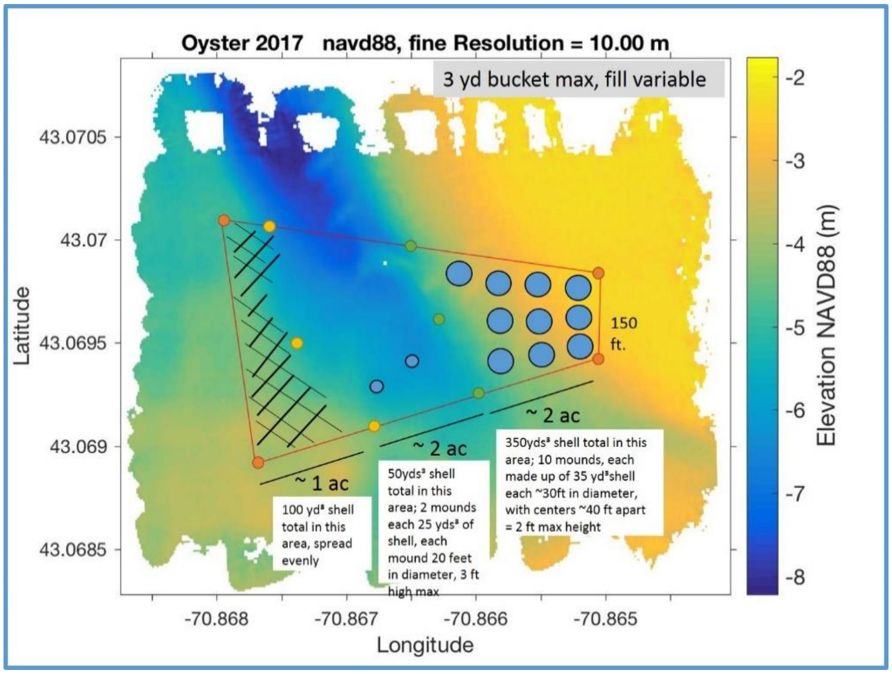


Figure 8: Mollusc shell deployment plan provided to the marine contractor projected onto multibeam sonar bathymetry map. Note that the shell base consisted of a total of 12 individual shell mounds and a thin layer of shell to be distributed in the cross-hatched area (Taken from Grizzle & Ward, 2018)

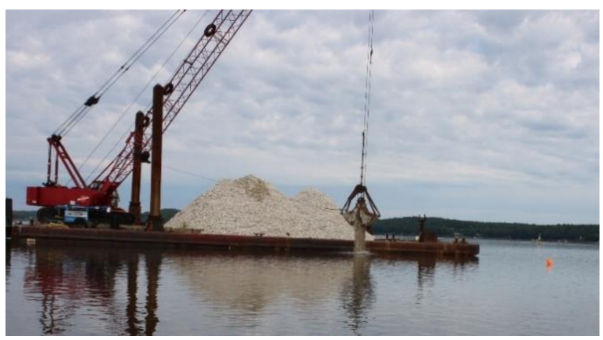


Figure 9. Barge deploying shell (a mix of clam and oyster shell) on the restoration site.

Woodman Point & Lamprey River:

In 2018, we worked in two general areas, a 2.5-acre site west of Woodman Point in Newington and two sites (1acre, 2 acre) at the mouth of the Lamprey River in the Town of Newmarket (Figure 10). Both sites were chosen due to their proximity to native oyster reefs. Prior to shell placement the sites were surveyed on June 12th and 13th, 2018 with underwater video to characterize bottom conditions and confirm that there was no eelgrass present at the site. Additionally, Dr. Lippmann of UNH CCOM provided high-resolution bathymetry data from a sonar survey of the site (see bathymetric methods section below). The imagery and bathymetric data were used to produce pre-construction maps of the restoration site and to design the shell pile deployment plan for the marine contractor, Riverside and Pickering. On June 27-30th 2018 the marine contractor, mobilized the barge with shell to the Woodman Point site. At Woodman

Point, 200 cubic yards of clam shell was deployed in piles in the northern portion and in a modest shell layer in the middle of the site between the piles and native reef (Figure 11). At the Lamprey region, 150 yards of shell was deployed at the two-acre site placed above the native reef and 100 yards of shell was deployed at the one-acre site downstream of the native reef (Figure 11).

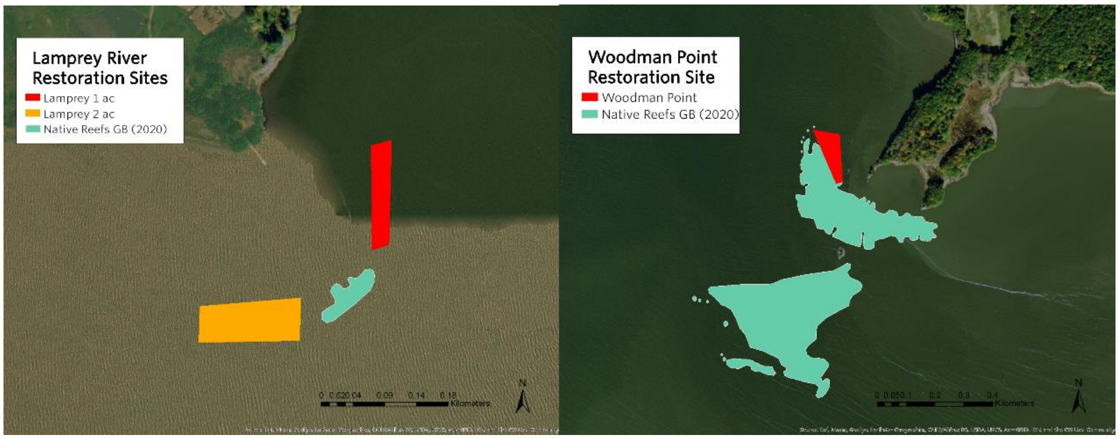


Figure 10. 2018 restoration sites: Lamprey (left) and Woodman Point (right) (red and orange). Compared to their native Lamprey (left) and Woodman Point (right) oyster reefs in turquoise.

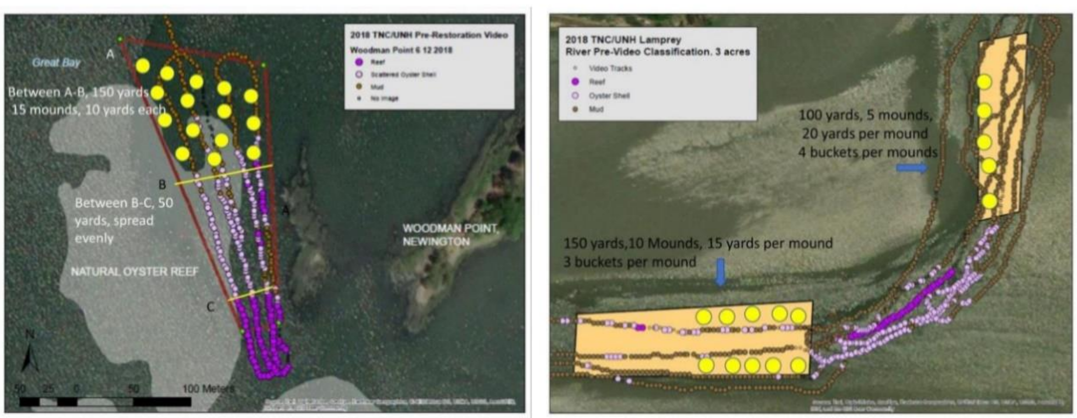


Figure 11: Pre-restoration bottom conditions and design plans for shell base construction at the two restoration areas based on towed underwater video maps. Woodman Point (left) and Lamprey River (right) (Taken from Grizzle & Ward, 2019).

Bathymetric Surveys

Dr. Lippmann of the University of New Hampshire CCOM was contracted to conduct bathymetric surveys over the Nannie Island, Woodman Point and Lamprey oyster reef restoration sites to examine sediment dynamics and sedimentation over time at each site. The general approach was to conduct detailed bathymetric mapping (with multi-beam sonar) prior to reef deployment, again 1 month after the shell was deployed (thought to settle out) and then several times over the next 1-2 years. Multiple surveys enabled the assessment and determination of depth changes in the shell mounds deployed.

Detailed bathymetric surveys were conducted with both the Coastal Bathymetry Survey System (CBASS) and the Zego Boat Survey System. "The CBASS is a Yamaha GP1200 waverunner equipped with 240 kHz multi-beam echosounder (Imagenex Delta-T), 192 kHz single-beam echosounder, Applanix POS-MV 320 inertial measurement unit, and custom navigation with display. The CBASS is capable of observing seabed water depths with vertical resolution of about 5-10 cm, and horizontal resolution of 10-25 cm in water depths ranging 1-20 m. The Zego boat is a 14 ft catamaran powered with an outboard motor, and equipped with the same instrumentation as the CBASS, and has resolution similar to the CBASS".

Surveys were conducted around high tide and typically lasted approximately four hours. Survey lines were spaced approximately 2.5 – 3.5 m, depending on conditions keeping the vessel on track, and cross-lines were done for each survey. Ping rates for the sonar ranged 3.75 hz to 10 hz, depending on multibeam range that depended on water depth. "The multi-beam data obtained from each survey was processed, filtered, and then gridded to 0.25 m, 1.00 m, and 2.50 m resolution. Raw elevations are relative to the WGS84 ellipsoid, and are then transformed to orthometric heights (relative to the NAVD88 datum) using software provided by the National Geodetic Survey (programs intg.f and htdp.f converted to MATLAB scripts). Note that mean sea level is within a few cm of NAVD88".

Oyster Spat on Shell Production

Dr. Grizzle and Ms. Ward of UNH follow the remote setting process for production of spat-on-shell as the general methods in Castagna et al. (1996) and Supan et al. (1999). Seasoned recycled oyster shell obtained from UNH and CCA shell recycling program was pressured washed, placed into cages, and moved into seawater setting tanks at JEL for remote setting. Shell transport, cleaning and tank preparation began in June in 2017 and 2018. Twelve (12) million larvae were obtained from Muscongus Bay Aquaculture, Bremen Maine in early July and placed into the setting tanks (Grizzle and Ward, 2018 & 2019). After settlement cages with SOS were moved to a nursery raft where they were held for about 2 months, then transferred to the restoration site and manually spread onto the shell base foundation.

2017 Oysters for Nannie Island

A setting success rate of about 25% (# of live spat produced [3,037,805] relative to the number of oyster larvae put into the tanks [12,000,000]) was determined on July 16, 2017 when the SOS were moved from the setting tanks to the nursery raft. Summary data of settling success by tank and subsequent live SOS by compartment on the raft is shown in Table 4. Deployment of SOS onto four specific piles in the constructed reef base occurred on September 23, 2017 after 10 weeks on the nursery raft. Before deployment, 80 oyster shells were collected from the raft, total SOS counted, and spat from 20 of these shells were measured to determine shell height (mm). At that time, approximately 730,000 live juvenile oysters were on the recycled oyster shell cultch, resulting in a 6% final remote setting/nursery raft success rate. At that time, the average shell height of the spat was 18.4 mm, with a range of 4 to 41 mm.

2018 Oysters for Woodman Point

Given the successful recruitment on the piles from the native reef at the Lamprey site, oysters were reared for deployment at Woodman Point. A setting success rate of about 8% (number of live spat produced [~1,000,000] relative to the number of oyster larvae put into the tanks [12,000,000]) was determined on July 16, 2018 when the SOS were moved from the setting tanks to the nursery raft (Table 1). This was a much lower setting success compared to 2017, but the survival on the raft in 2018 was much higher than 2017. Summary data of settling success by tank and subsequent live SOS by compartment on the raft is shown in Table 5. About 600,000 live SOS were deployed onto the Woodman Point restoration site on September 4, 2018, after 9 weeks on the nursery raft. At that time, 120 oyster shells were collected from the rafts, all live SOS counted, and 120 live spat measured to determine mean shell height (mm). The average shell height of the spat was 22.8 mm, with a range of 4 to 55 mm.

Table 4. Summary data for spat-on-shell production from remote setting tanks (data from July 16, 2017) and nursery rafts (data from September 23, 2017; see Task 4 below). SOS = live oyster spat-on-shell (taken from Grizzle & Ward, 2018). Total # SOS produced in remote setting tanks was 3,037,805 (± 387,171 spat). Total # spat produced on raft was 729,669 (± 81,902 spat).

Setting Tank	**Mean # Spat per Shell**	**# Cages in Tank**	**Mean # Shells (Cultch) in each cage**
A	33.6	48	454
B	31.3	36	454
C	53.7	40	454
D	44.6	40	454
	Mean: 40.8 (± 5.2)	Total: 164 cages	

Raft	**Mean # Spat per Shell**	**# Cages on Raft**	**Mean # Shells (Cultch) in each cage**
A	12	48	454
B	11	36	454
C	9	40	454
D	7	40	454
	Mean: 9.8 (± 1.1)	Total: 164 cages	

Table 5. Live SOS from the remote setting tanks (top) and nursery raft (bottom) in 2018. Taken from Grizzle & Ward, 2019). Total # SOS produced in remote setting tanks was 1,056,746 (± 390,996 spat). Total # spat produced on raft was 625,484 (± 365,944 spat).

Setting Tank	Mean # Spat per Shell	# Cages on Raft	Mean # Shells (Cultch) in each cage
A	10.8	48	454
B	36.5	36	454
C	12.0	40	454
D	9.9	40	454
	Mean: 17.3	Total: 164 cages	

Raft	Mean # Spat per Shell	# Cages on Raft	Mean # Shells (Cultch) in each cage
A	10.9	48	454
B	11.5	36	454
C	9.0	40	454
D	9.5	40	454
	Mean: 10.2	Total: 164 cages	

Oyster Conservationist Program

The Oyster Conservationist (OC) Program is a community engagement citizen science oyster gardening program during which volunteers care for and manage a cage of SOS for 8 weeks in the summer. This includes data collection on growth of the spat and their survival throughout the season. Volunteers are also given a bag of clam shell to measure wild recruitment from the wild oyster reefs at their specific location. Participants in the program include families, individuals, businesses, and schools. Though this program we engage with 300+ community members around the Great Bay Estuary. In addition, spat count volunteers from the general public are recruited by Nature Groupie to make the initial and final SOS counts and measurements.

In 2017, the OC program had 89 sites across 15 towns in New Hampshire and Maine across the entire estuary. The total number of SOS delivered to OC's was estimated to be 66,147 spat at <1mm in size. The average final size of the SOS was 23.3 ± 1.6mm (mean ± standard error) with ending sizes ranging from 4 to 55 mm. OC sites were grouped by location for spatial analysis and comparison. Growth was highest in the Cocheco River, Oyster River, and Bellamy River with the slowest growth in the Piscataqua River and Winnicut River (Figure 12). This pattern of growth reflects warmer temperatures and higher phytoplankton concentrations typically in the tributaries of the Great Bay Estuary.

OC's in 2017 raised a total of 42,854 SOS with a total survival of 64%. Highest survival occurred in the Lamprey and Bellamy Rivers, with lowest survival in the Winnicut River and Little Bay (Figure 13). Low wild recruitment rates were recorded for 2017 on the bagged clam shell, but this could have been related to delivery of the cages occurring after the wild oyster reefs spawned.

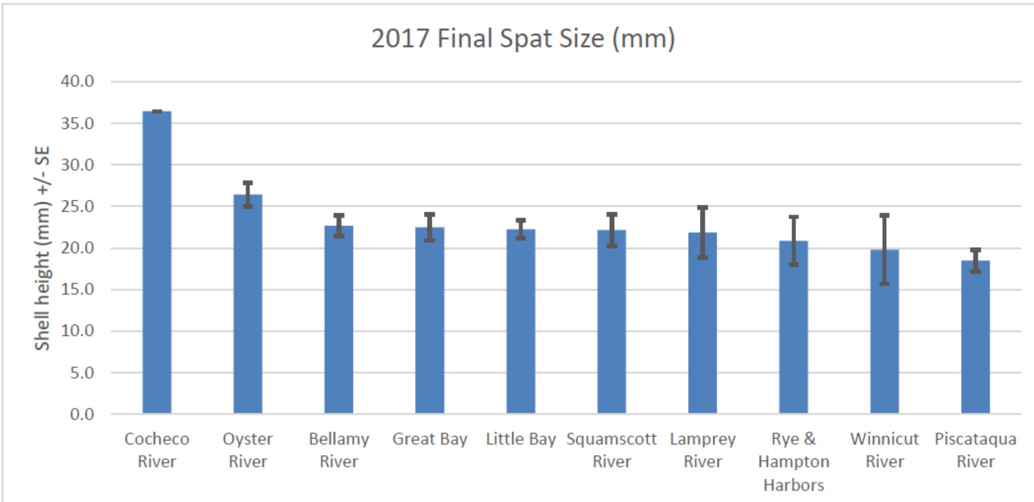


Figure 12. Average final size of oyster SOS (mm) based on location, 2017 ± SE. (Moeser, 2017 Oyster Conservationist Report).

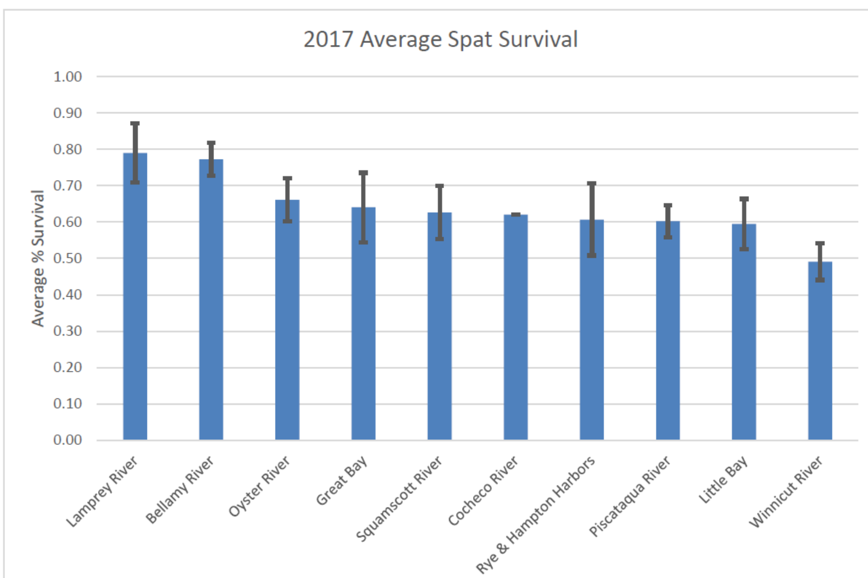


Figure 13. Average percent survival (± SE) by location in 2017 (Moeser, 2017).

In 2018, there were 89 OC sites spread across 16 towns in New Hampshire and Maine. We delivered an estimated 27,122 oyster SOS to the OC volunteer sites at <5mm in size. The average final size across all sites was 32.1± 1.06mm (mean± standard error). Sizes ranged from 7 to 65 mm. OC sites were grouped by location to spatially analyze and compare. Sites in the Bellamy River, Oyster River, and Little Bay saw the fastest growth like previous years (Figure 14). While sites in the Squamscott and Winnicut River saw the slowest growth.

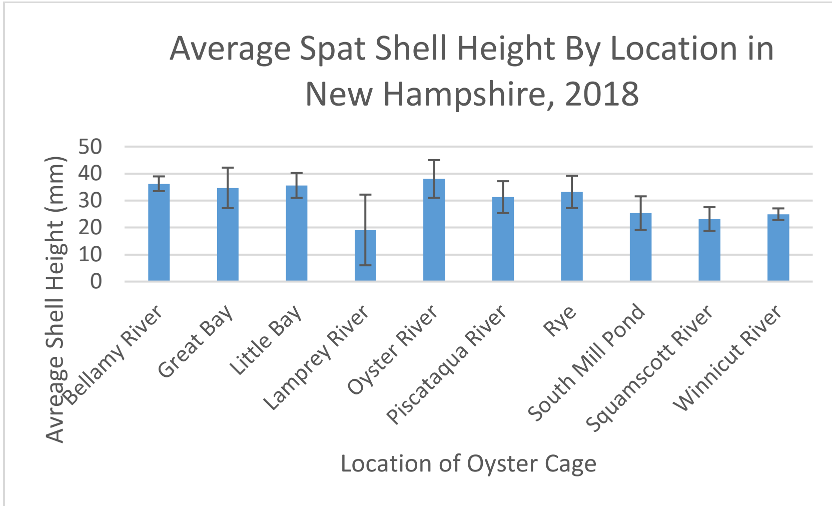


Figure 14. Average oyster spat shell length (used to measure growth) by location in New Hampshire, 2018 ± SE (Group, 2018 Oyster Conservationist Report).

2018 was an excellent year for oyster growth and survival, both numbers on average were higher than previous years, which can be attributed to excellent growing conditions in Great Bay Estuary (Personal Communication). OC's returned an estimated total of 22,482 SOS with an overall 83% survival rate. Sites with the highest survival were the Bellamy River, Oyster River, and Little Bay, while lowest survival occurred in the Squamscott River most likely due to burial from sedimentation and predation (Figure 15). Many of the sites saw over 100% survival which can be attributed to wild spat recruitment and highly productive wild reefs in 2018 (Anecdotal evidence).

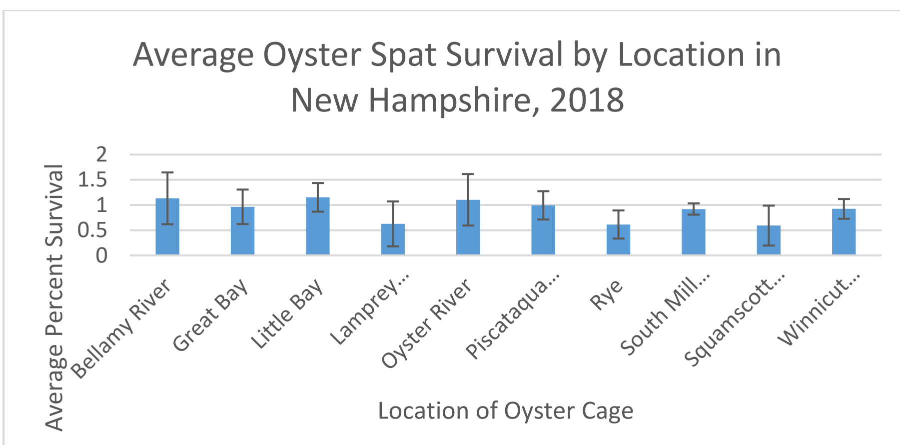


Figure 15. Average percent of oyster survival (± SE) in 2018 by location. Survival over 100% can be attributed to settlement of wild spat in the OC cages (Group, 2018 Oyster Conservationist Report).

Post Construction Monitoring and Results

Detailed bathymetric mapping (with multi-beam sonar) after deployment of shell, and then several times over the next 1-2 years was conducted to determine the shape and persistence of the shell mounds to examine sediment dynamics at the site. Detailed timeline of bathymetric surveys can be found in Appendix 1. The multi-beam data were processed in a similar manner for all surveys and were gridded to 25 cm resolution with grid cells that correspond to the first survey. Difference maps were produced to track the individual mounds at the sites over time. These maps were used to guide physical inspection of the deployed oyster mounds with video and for biological tong sampling. Video sampling was also conducted at the sites to assess the shape and size of the reef. Biological sampling was conducted at the sites where SOS was deployed to determine growth and survival of the reared oysters and to assess natural recruitment onto the shell mounds. Biological samples were also taken from nearby to assess if restoration success is affected by distance to the nearest population of adult/potentially reproducing oysters. Results of the shell mounds construction, termed the 'reef base' and oyster densities overtime are laid out by site below.

Nannie Island

Reef Base

The post construction survey was conducted 34 days after shell deployment on 31 July 2017. A difference map was produced by subtracting the bathymetry collected on 12 June 2017 from the bathymetry obtained on 31 July 2017. The shell mounds deployed are clearly shown in the difference map shown in Figure 16 where there is a 20-50+cm increase in elevation after deployment. Surveys over the next 2 years monitored the deployed shell mounds. Changes in the elevation in the east-west direction across the center of each mound were determined from each survey at 0.25 m resolution. Figure 17 shows how the mound height evolves over time. In general, all the mounds at the restoration site did not significantly evolve over the 2.5-year period after deployment (included two winter icing periods). A few mounds changed in small details around the edge, which may be due to the shell settling or currents at the site.

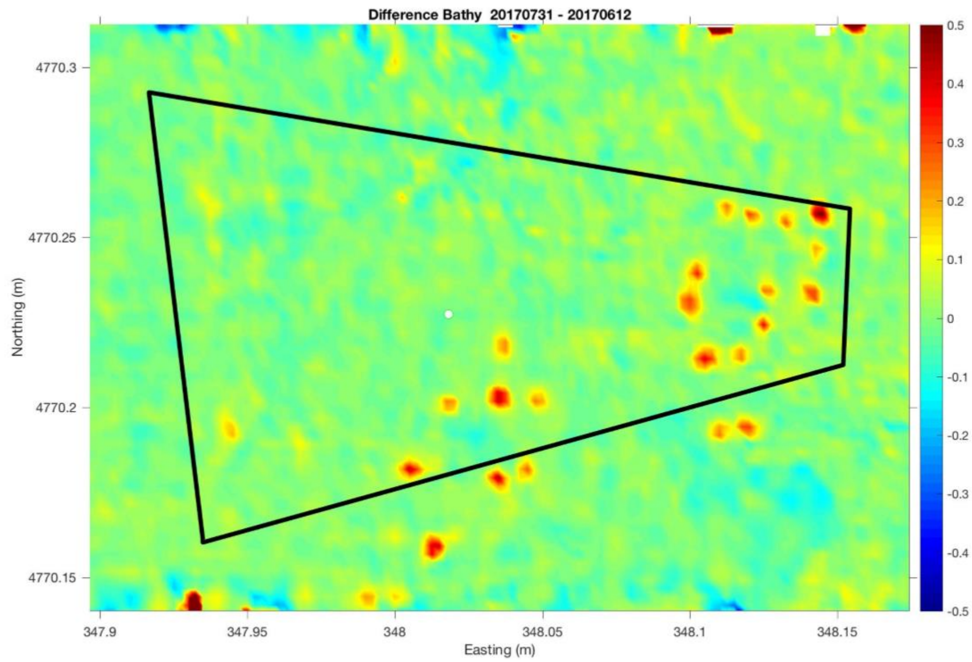


Figure 16. Difference elevation map between surveys obtained at Nannie Island on 12 June and 31 July 2017. Locations of deployed oyster shells are easily identified by elevated mounds (reddish colors). Horizontal resolution is 25 cm. Elevation differences are in m and given by the colorbar on the right-hand-side. Horizontal coordinates are km in eastings and northings. The solid black line outlines the region encompassing the 5-acre artificial oyster reef region (Taken from Lippmann, 2019).

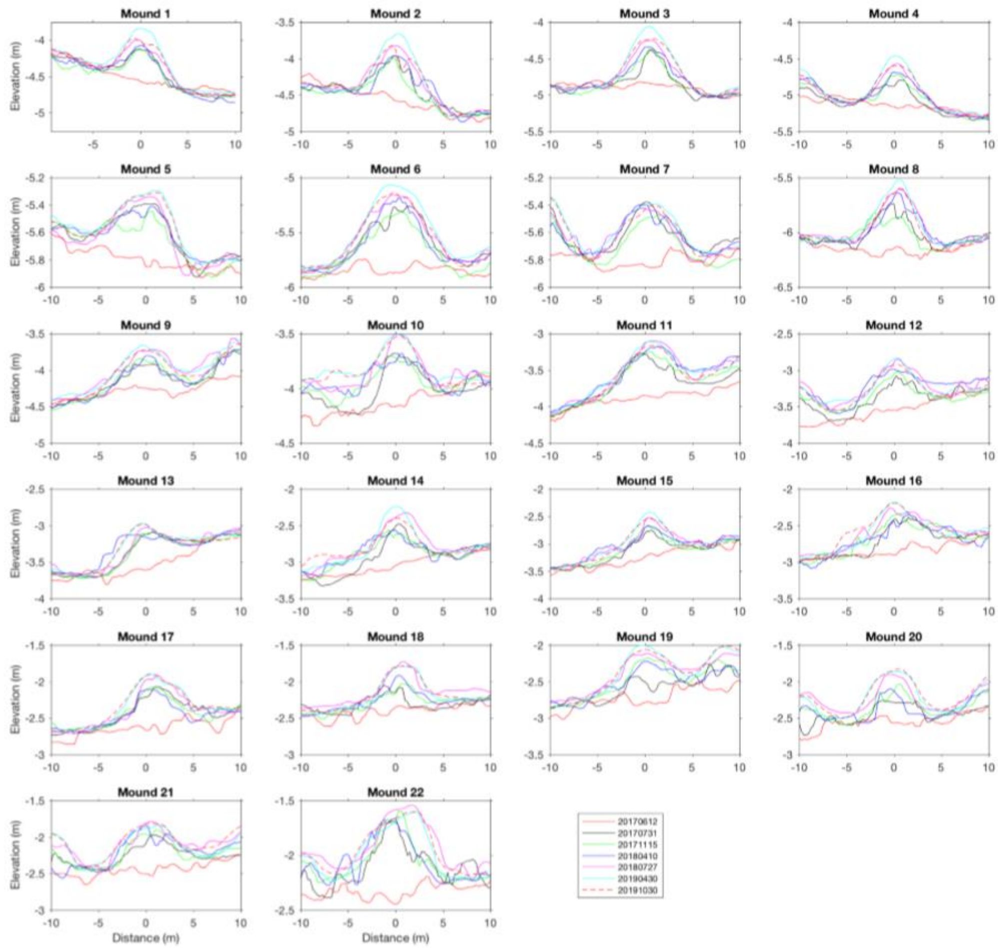


Figure 17: Bathymetric elevation profiles (in m relative to NAVD88) across all mounds at the Nannie Island restoration site. Survey dates are indicated in the legend. Horizontal axis is distance in m along an east-west transect relative to the center of the mound identified from the 31 July 2017 survey. All mounds were identified and show little change in all surveys after deployment of shell in the summer of 2017 (Taken from Lippmann, 2019, Appendix 1).

Oysters:

In 2017, replicate patent tong samples were taken from October 31–November 2, 2017 on several shell mounds where the SOS had been placed in the summer of 2017 on Nannie Island restoration site (Grizzle & Ward, 2018). Tong samples from the shell mounds resulted in high densities (474/m^2) of live oysters on the recycled oyster shell, confirming the success of the SOS deposition process, and indicating good initial survival. However, only one live wild oyster spat was collected that had set on clam shell used to construct the reef base, indicating very low natural recruitment to the 2017 restoration site during sampling in 2017. Sampling of the site in 2018, revealed that SOS survival on oyster shell was very low (1.5m^2) and only two wild spat had set on the clam shell (Table 6). Sampling in 2018 at the native Nannie Island site resulted with one live oyster and no natural set (Table 6).

Woodman Point

Reef Base

Bathymetric mapping was conducted September 16, 2018 approximately 1 month after shell deployment. The difference map shows the presence of 14 distinct shell mounds (Figure 18). The mounds did not evolve significantly over the 1.25-year monitoring period, individual mound profiles are shown in Figure 19. Video mapping of Woodman Point was conducted on October 1, 2018. Water clarity was good, and the video recorded imagery confirmed the general locations of the shell mounds in the greater portion of the restoration site. Due to the shallow depth of the northwest corner of the site, that area was not comprehensively surveyed with video (Grizzle & Ward, 2019).

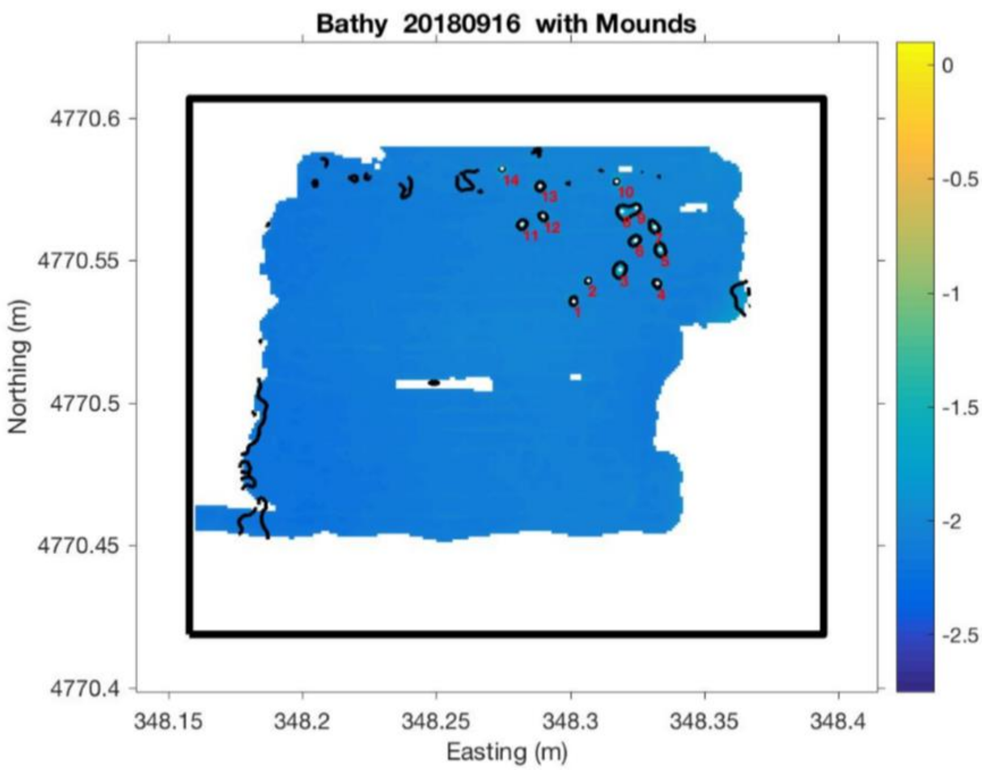


Figure 18: Bathymetric map of Woodman Pt. obtained on 16 September 2018 also showing the outlined regions of the oyster mounds identified by the difference map (Figure 13). Locations of mound elevation maxima are indicated with white dots within the contours. Mounds are numbered from 1 to 14. Background bathymetry has resolution of 1.0 m. Elevations are in m relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-handside. Horizontal coordinates are km in eastings and northings (Taken from Lippmann 2019).

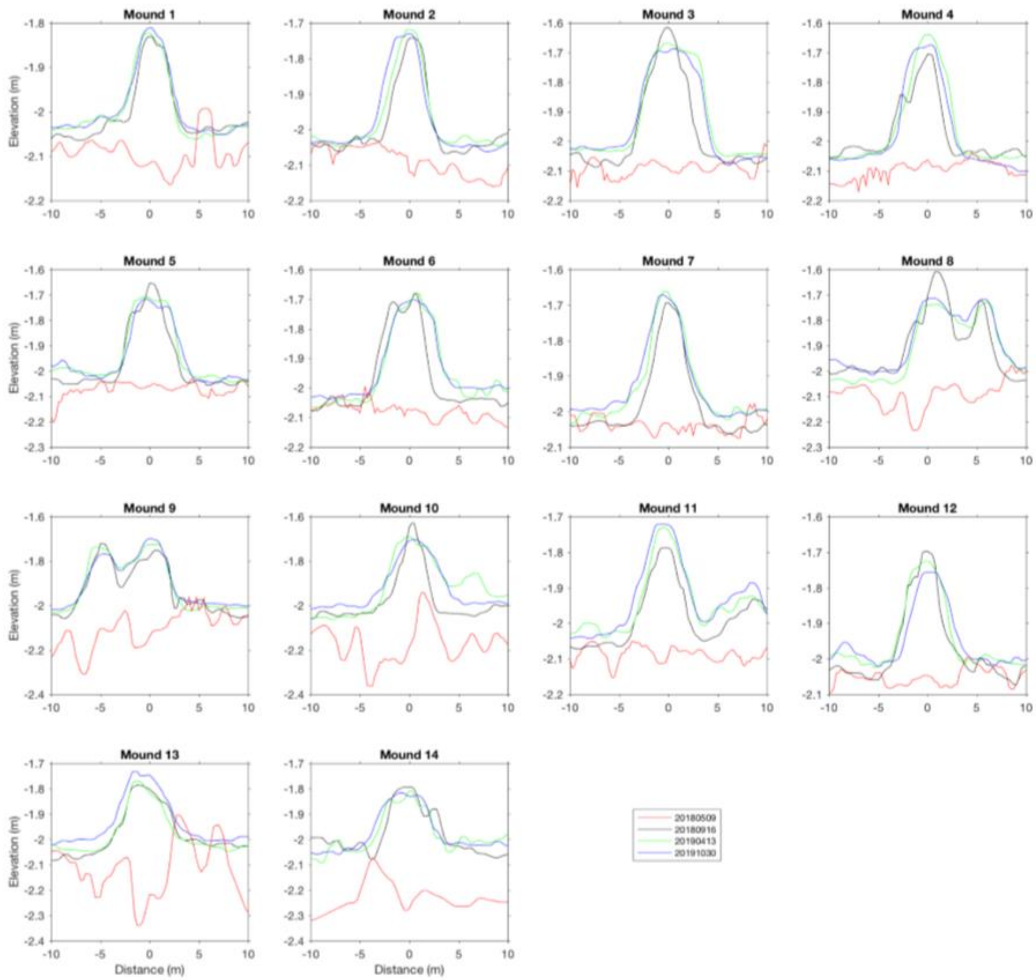


Figure 19: Bathymetric elevation profiles (in m relative to NAVD88) across all mounds for Woodman Pt. Survey dates are indicated in the legend. Horizontal axis is distance in m along an east-west transect relative to the center of the mound identified from the 16 Sep 2018 survey. All mounds (1-14) show little change over the 1.25-year monitoring period (Taken from Lippmann, 2019).

Oysters:

Patent tong sampling was conducted on October 11, 2018 from several constructed shell mounds on the Woodman Point restoration site and natural reef (Figure 20, Table 6). These samples quantified the remotely set SOS on the "seeded" mounds, density was highly variable with an average of 61.4m^2 (Table 6). Earlier in the year the mounds were quantitively sampled with hand tongs, at which time the samples found very few natural spat on the calm shell, no spat were found in the patent tongs confirming very little natural recruitment. Sampling at the Woodman Point native reef revealed low densities of live oysters in 2018 (Table 6).

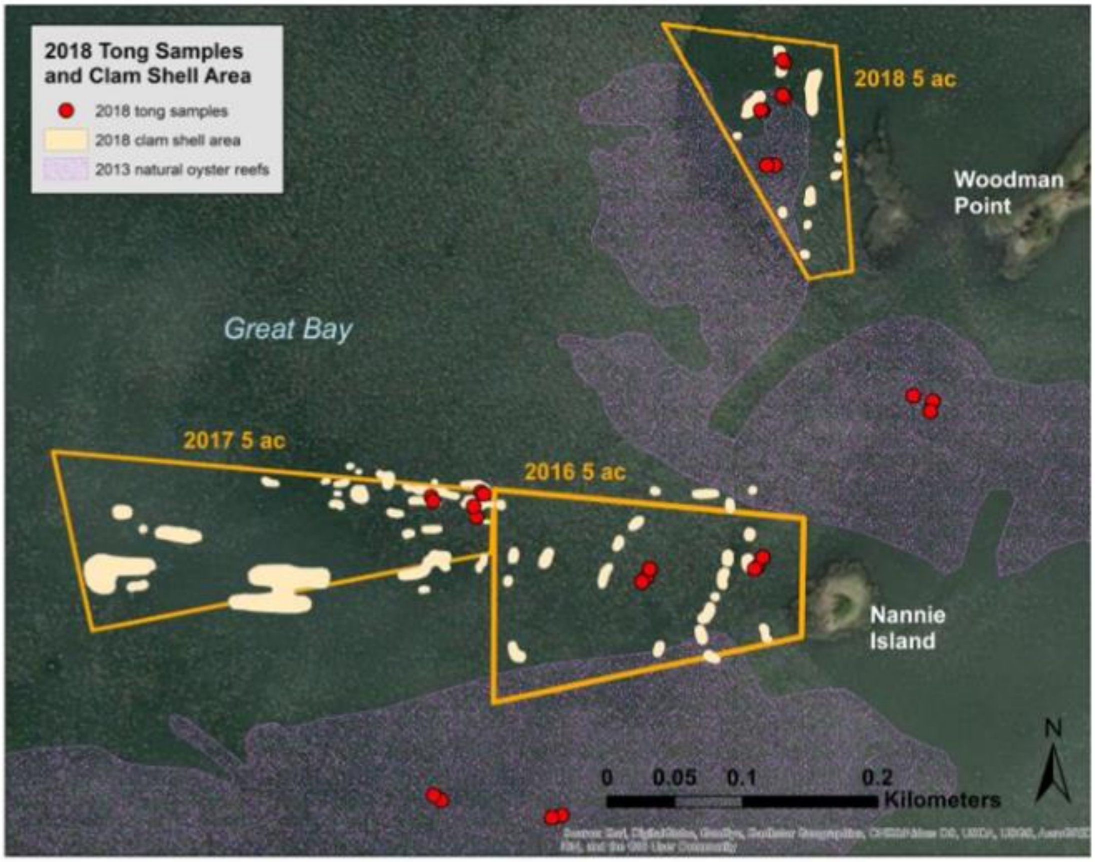


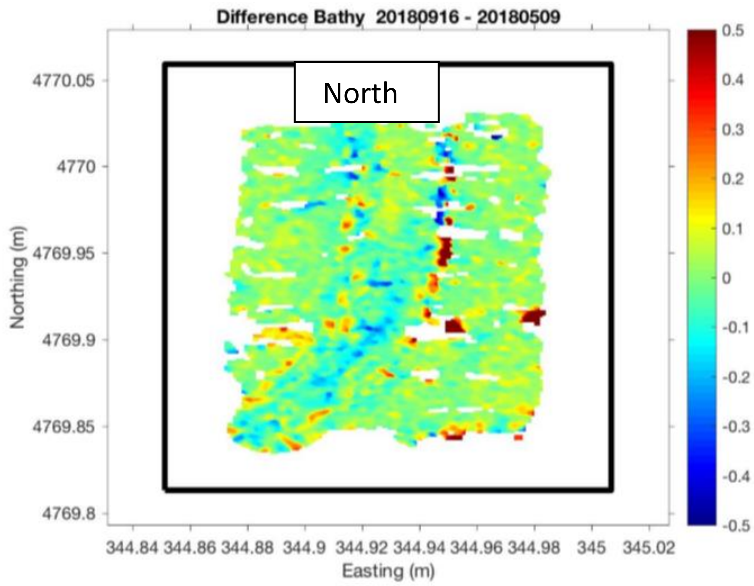
Figure 20: Tong sampling locations at the Woodman Point and Nannie Island sites (Taken from Grizzle & Ward, 2018).

Lamprey

Reef Base:

Bathymetric mapping was conducted approximately one month after the reef base construction in September of 2018 at both the northern and southern site. For the north site, the evolution of the bathymetry or low relief of the deployed shell mounds at the north site precluded confident extraction of oyster mounds and therefore no mounds were identified (Figure 21, top). It is possible that the shell at this site sank into the mud after deployment (personal observation). For the South site, the difference map reveals the presence of 10 identifiable mounds (Figure 21). The profiles showed that there was little evolution in the mounds over the 1.25-year monitoring period (Figure 22). Video mapping of the Lamprey River sites was conducted on October 3, 2018. Water clarity was good, and video confirmed the general locations of the shell mounds as well as locations of many individual mounds (Figure 23).

During the summer of 2019, 3 mounds at the Lamprey restoration sites were eliminated owing to concern over navigation safety. The changes in these areas are readily seen in the difference bathymetry maps for both the southern and northern Lamprey regions.



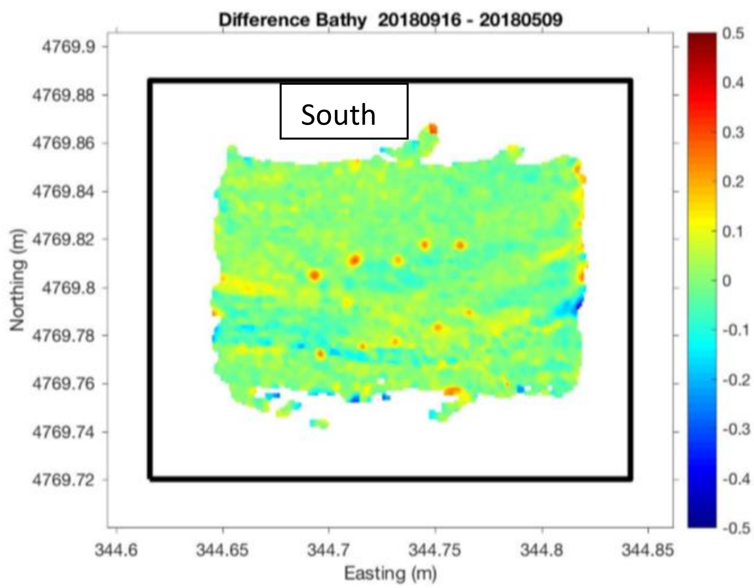


Figure 21. Difference elevation maps between initial surveys conducted on 09 May 2018 and surveys conducted on 16 September 2018. Locations of deployed oyster shells are easily identified by elevated mounds (reddish colors) at the Lamprey south (bottom) difference map. However, differences for the Lamprey north (top) region are much more difficult to discern. Horizontal resolution is 100 cm. Elevation differences are in m and given by the colorbar on the right-hand-side. Horizontal coordinates are km in eastings and northings (Taken from Lippmann, 2019).

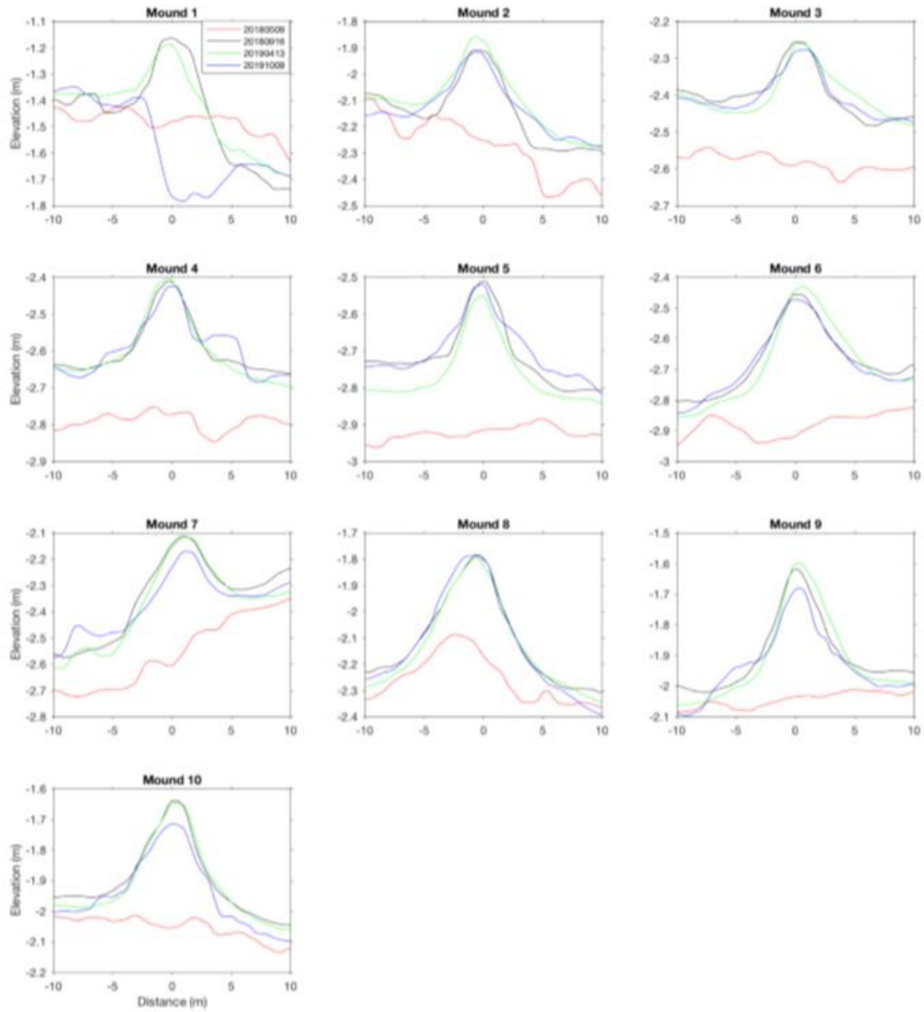
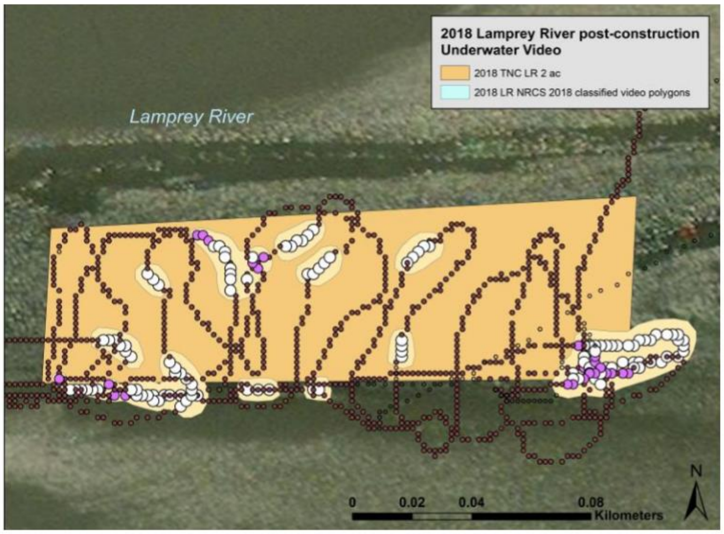


Figure 22: Bathymetric elevation profiles (in m relative to NAVD88) across all mounds for Lamprey south. Survey dates are indicated in the legend of mound 1. Horizontal axis is distance in m along an east-west transect relative to the center of the mound identified from the 16 Sep 2018 survey. Mounds 2-10 show little change. Note that mound 1 was removed in the summer of 2019 (Taken from Lippmann, 2019).



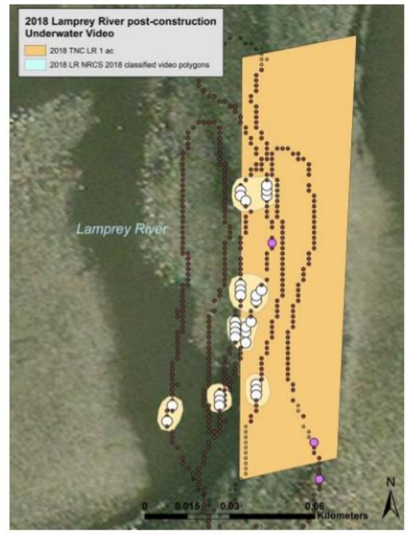


Figure 23: Classified video shiptracks for western (left) and northern (right) Lamprey River restoration sites (taken from Grizzle & Ward, 2019).

Oysters:

Tong sampling was conducted on October 12 from several constructed shell mounds at the restoration sites and nearby native reef between the two restoration sites (Figure 24). Tong data from both Lamprey River sites indicated dense natural recruitment to the constructed shell mounds (Table 6). Patent tong samples were only taken from three shell mounds, but all three had abundant live oyster spat from natural recruitment, with a mean of 132 spat/0.1 m^2, compared to a mean of 59 live oysters/0.1 m^2 (all size classes combined) from the nearby natural reef (Table 6). The 2018 data show that the mouth of the Lamprey River had positive recruitment to both shell mounds and natural reef and may be an area for potential future oyster reef restoration efforts.

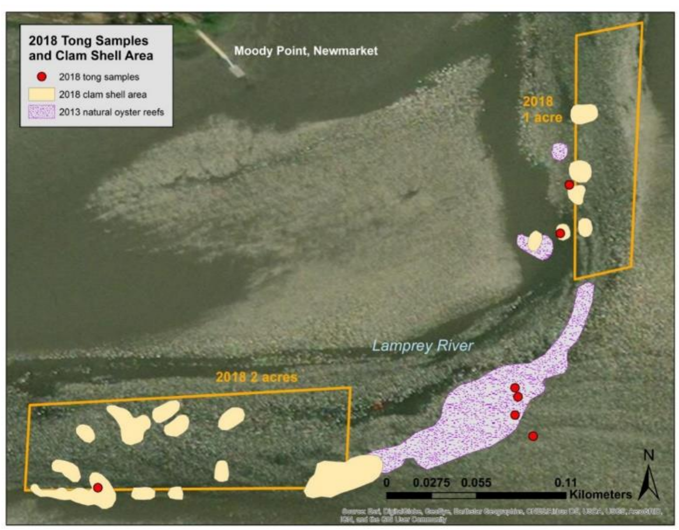


Figure 24: taken from Ray Locations of constructed shell mounds (“2018 clam shell area”), tong samples, and adjacent natural reef for 2018 Lamprey River restoration sites.

Table 6. Patent tong data from 2018 sampling of 2017 and 2018 restoration sites and nearby natural reefs (gray shading). NI = Nannie Island, WP = Woodman Point. Note that data for "oyster" substrate on restoration sites represents live spat-on-shell from remote setting process used to "seed" the shell bases (taken from Grizzle & Ward, 2019).

Sampling Date	Site	Restoration Acreage	Lat_DD	Long_DD	Substrate	# of live oysters/0.1m^2
10/11/2018	NI 2017	5.0	43.06967	-70.86515	clam	2
10/11/2018	NI 2017	5.0	43.06974	-70.86517	clam	0
10/11/2018	NI 2017	5.0	43.06983	-70.86512	oyster	1
10/11/2018	NI 2017	5.0	43.06982	-70.86510	clam	0
10/11/2018	NI 2017	5.9	43.06980	-70.86545	oyster	1
10/11/2018	NI 2017	5.0	43.06977	-70.86544	clam	0
10/11/2018	NI natural	Natural	43.06768	-70.86458	oyster	0
10/11/2018	NI natural	Natural	43.06767	-70.86465	oyster	1
10/11/2018	NI natural	Natural	43.06778	-70.86538	oyster	0
10/11/2018	NI natural	Natural	43.06782	-70.86543	oyster	0
10/11/2018	WP, 2018	2.5	43.07200	-70.86317	oyster	1
10/11/2018	WP, 2018	2.5	43.07200	-70.86322	oyster	1
10/11/2018	WP, 2018	2.5	43.07237	-70.86325	oyster	1
10/11/2018	WP, 2018	2.5	43.07237	-70.86326	oyster	0
10/11/2018	WP, 2018	2.5	43.07245	-70.86310	oyster	31
10/11/2018	WP, 2018	2.5	43.07247	-70.86312	oyster	41
10/11/2018	WP,2018	2.5	43.07268	-70.86310	oyster	278
10/11/2018	WP, 2018	2.5	43.07270	-70.86312	oyster	138
10/11/2018	WP, 2018, natural	Natural	43.07043	-70.86212	oyster	2
10/11/2018	WP, 2018, natural	Natural	43.07037	-70.86213	oyster	5
10/11/2018	WP, 2018, natural	Natural	43.07047	-70.86225	oyster	2
10/12/2018	LR, North, 2018	1.0	43.06646	-70.90473	clam	23
10/12/2018	LR, North, 2018	1.0	43.06620	-70.90478	clam	74
10/12/2018	LR, South, 2018	2.0	43.06480	-70.90733	clam	301
10/12/2018	LR, Natural	Natural	43.06508	-70.90493	oyster	Didn't count
10/12/2018	LR, Natural	Natural	43.06520	-70.90503	oyster	34
10/12/2018	LR, Natural	Natural	43.06530	-70.90502	oyster	94
10/12/2018	LR, Natural	Natural	43.06535	-70.90503	oyster	48

Conclusion

Cultch deployed as a reef base was successful and has persisted into 2020 at the restoration sites of Nannie Island, Woodman Point and the Lamprey. Bathymetric surveys conducted over the time period have yielded important results that better our understanding of sediment dynamics at these sites. The shell piles at Nannie Island and Woodman Point have collected very little natural set, significantly less that we had hoped. We believe this is due to the low adult densities on the two natural reefs and is discussed in further detail in Chapter 4. The SOS deployed at Nannie Island restoration site had low survival which may be due to heavy predation at this site. We did find that SOS survival was higher at the Woodman Point restoration site. Following this result, we chose Woodman Point for the SOS deployment site in 2019 and 2020. The Lamprey River restoration site that remains (subtracting the piles removed per request of the ACOE), has collected a natural set from the nearby productive native reef. The Lamprey river site shows great promise for natural reef formation, but due to the restriction from the ACOE no further restoration can take place within the navigation channel. The deployment and monitoring of these three sites has produced valuable information for the site selection criteria and indicators and identifying future sites for restoration described in section IV.

III. Stakeholder Engagement

Background

The Piscataqua Region Estuaries Partnership (PREP) in collaboration with The Nature Conservancy (TNC), developed a public participation plan to clearly outline the context and goals of the stakeholder engagement process of the "Oyster Restoration by Design" project. The full details of the public participation plan can be found in Appendix II. Fourteen formal meetings were held between PREP and TNC between January and November 2018 in order to discuss and prepare all aspects of this process, including identification of stakeholders, meetings, focus groups, workshops, data collection and analysis. At the beginning of the process a steering committee was established that consisted of multiple stakeholders from organizations including TNC, PREP, NH Department of Environmental Services, NH Coastal Program, NH Fish & Game, Great Bay National Estuary Research Reserve (GB NERR), NH Sea Grant, and Natural Resources Conservation Service (NRCS). The primary role of the Steering Committee was to oversee and guide the public involvement process, with an emphasis on who to involve, how to involve them, and how to clarify the decision-making process.

TNC staff reviewed historical restoration projects and applied current data to generate a basemap (Figure 4). This map was used to establish evaluation criteria for future restoration work. The following criteria were included to evaluate the likelihood of oyster restoration success: results of historical restoration projects, site specific oyster growth and survival, substrate type and sediment dynamics, proximity to native reefs, hydrodynamics, physical and environmental conditions, presence and movement of ice. Potential site-use conflicts were also considered, such as aquaculture and recreational use, in addition to the ease of permitting. The Steering Committee was given the opportunity to raise concerns and make suggestions to help refine the scope of the project and accompanying process. The following concerns were identified:

- ***Spatial conflict of oyster & eelgrass restoration:*** In addition to oysters, eelgrass is viewed as a highly valuable habitat in Great Bay. Areas suitable for oyster restoration may also be suitable for eelgrass restoration or areas of historic eelgrass beds. Therefore, certain agencies and scientists may oppose oyster restoration in areas they view as better suited for eelgrass.
- ***Habitat conversion:*** While oyster reefs are viewed by many as a valuable habitat, the creation of a reef converts the habitat that currently exists at the restoration

site, such as mudflat. Some permitting agencies and scientists may be concerned with this conversion.

- ***Balancing restoration & future shellfish aquaculture areas:*** There are limited areas in Great Bay where oyster growers may lease space to raise oysters for harvest. Growers may, therefore, oppose the creation of an oyster restoration site, which is closed to harvesting, established in an available lease area.
- ***Landowners not wanting visual signs of restoration work:*** Restoration efforts require the use of barges and machinery that may not be visually appealing to those abutters of such projects. Therefore, landowners may have concerns or objections to such work near their property along the water.
- ***Restoration interfering with recreational use:*** Recreationalists such as boaters, kayakers, recreational harvesters, and anglers may be concerned that restoration activities block or hinder their access to the water resource they use for recreation.
- ***Project permitting:*** Projects within NH wetlands are significantly regulated. State and federal permitters, as well as local planning boards and conservation commissions, will need to be aware of and authorize any restoration project that is to take place in Great Bay.
- ***Improving Great Bay water quality:*** There are many individuals and organizations actively working with the interest of improving the water quality in Great Bay. Although oysters play a role in this effort, it often means striking the right balance for different habitats. Therefore, those stakeholders would likely want to have a voice in this process.
- ***Opportunities to be involved in restoration:*** Stakeholders, such as growers, landowners, municipalities, etc., may want to be involved in the restoration planning, influencing the decision and encouraging restoration effort.

Engagement Process

Given that there is a high density of local organizations and individuals working on water quality and ecosystem function in the Great Bay Estuary and the number of activities, values, and resources that could be affected by restoration efforts, the level of stakeholder interest was very high. Major interested groups focused on wetlands, restoration and ecosystems of the Great Bay Estuary consisted of: 1) local scientists and experts 2) local environmental organizations and NGOs, 3) Regulators, permitters, conservation and municipal boards 4) oyster growers and harvesters 5) landowners and abutters of the restoration site(s) and 6) recreationalists. Several of these groups provided input for the decision-making process. Some interest was based on a spatial conflict concern with many interested in the learning or implementation of future oyster restoration efforts.

To initiate the process of engaging with stakeholders TNC utilized the base map (Figure 4, Chapter 1) as a starting point in discussions to develop options for future sites and methodologies. A range of key stakeholders were engaged individually or in small groups to help discuss and identify potential restoration sites that were displayed on iterative maps used for further stakeholder meetings. There were three phases (outlined below) that focused on input from different classifications of stakeholders: 1) technical reviewers, 2) regulatory stakeholders, and 3) aquaculture and social interest stakeholders. Figure 25 outlines the steps and stakeholder involved in each step of the process. Maps were revised throughout each phase considering the technical and non-technical concerns of stakeholders. These three phases were held prior to a workshop where an inclusive and diverse set of stakeholders met to discuss and evaluate options. Communication of the overall "Restoration by Design" project was made public through means of direct communications and emails, an informational handout, and newsletter articles. The communications provided contact information for interested parties and encouraged interested individuals to participate at the workshop. Most of the stakeholders in phase 1-3 were involved in the workshop (Figure 25).

- ***Phase 1:*** Conducted a series of individual meetings and interviews with technical reviewers to determine sites in the Great Bay Estuary that are physically and environmentally appropriate for oyster restoration. The main topics discussed included: physical site suitability, sediment dynamics, ***Spatial conflict of oyster and eelgrass restoration***, proximity to native reefs and population dynamics.
- ***Phase 2:*** A focus group first met followed by individual meetings with regulators and permitters to evaluate sites in the Great Bay Estuary for restoration based on current and/or future rules and regulations. This group's discussion focused on permitting and alternative or new methodologies to confirm whether specific sites are permittable or not. The larger group also discussed habitat conversion. A follow up conversation with NH Fish and Game and DES discussed ***Balancing restoration & future shellfish aquaculture areas.*** It was decided that when possible, active and available areas of oyster aquaculture are avoided in siting potential restoration sites. ***Habitat conversion*** was also discussed by regulatory actors concerned with habitat conversion.
- ***Phase 3:*** A series of meetings with a sub-sample of growers were held to discuss and develop options and gather feedback based on their concerns and perspectives. The main topics of conversation with the growers were ***Balancing restoration & future shellfish aquaculture areas,*** opportunities to be involved in restoration, and restoration methodologies. Organizations whose goals include improving water quality in the Great Bay Estuary were interviewed to gain further insight on ***Improving Great Bay water quality***.

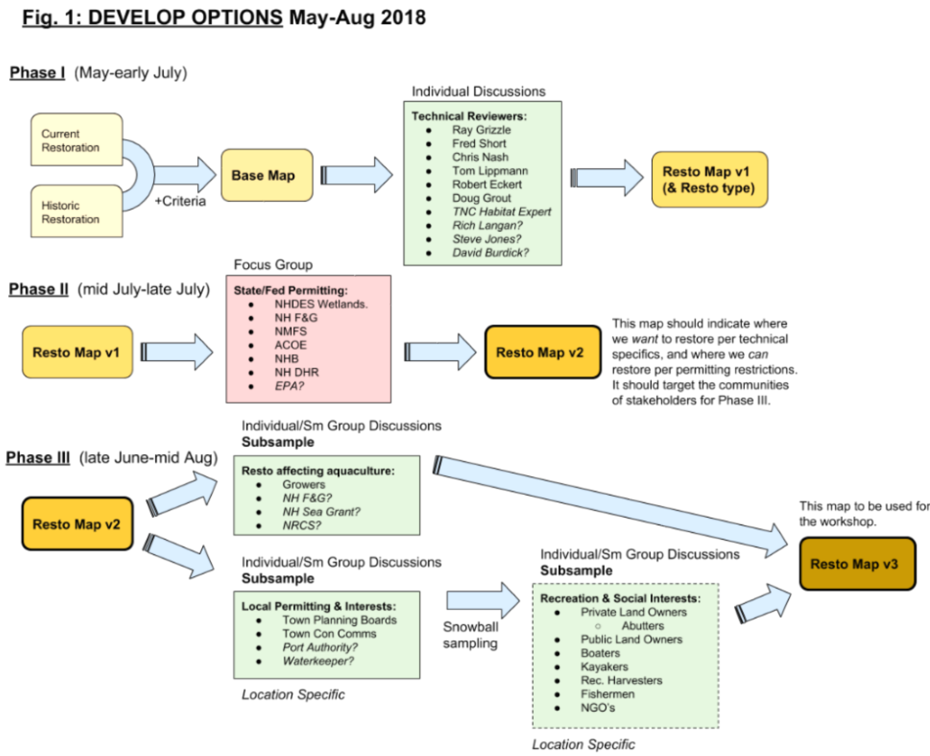


Figure 25: conceptual model for Phases 1-3 of the stakeholder engagement process.

Workshop

Following the completion of Phases 1-3, the stakeholder engagement process culminated in a workshop that was held on August 25, 2018. The workshop was comprised of both small and large group discussions. Stakeholders discussed the options developed for potential restoration sites to identify preferred options. The primary objective was to develop as high a level of consensus as possible on the preferred options and methodologies. A general overview of past restoration sites, current science related to sediment mapping, aquaculture areas, water classification as defined by DES and restoration techniques were reviewed as context and background for the work session. The workshop was broken down into two main components:

1) Site Selection

2) Science Cafes

Site Selection

Dr. Laferriere, Coastal and Marine Director for TNC, explained and presented a map of possible options along with site suitability details to the group for discussion (Figure 26). Three sites were removed from the options during technical and social review in Phases 1-3 (“Great Bay”, South of Adams, and Bellamy River) due to poor sediment dynamics at the Great Bay sites and dam removal within the Bellamy River. The remaining sites for evaluation were: Lamprey, Squamscott, Nannie Island, Woodman Point, Adams Point/Footman Islands, Oyster River, Three Rivers/ Piscataqua (Figure 26).

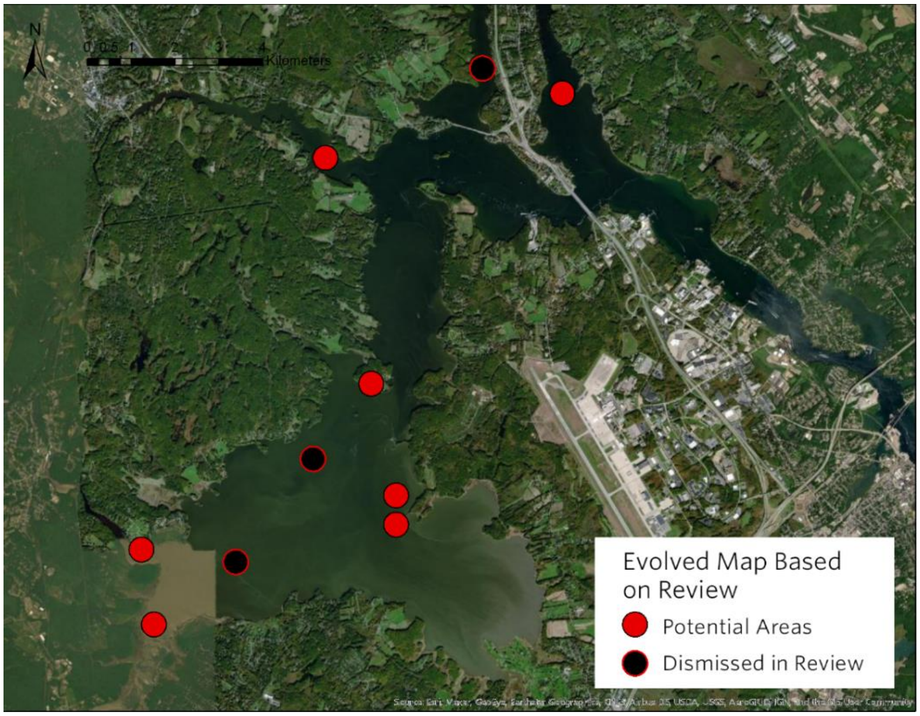


Figure 26: Base map of restoration sites used for discussion during the workshop. Areas in red were potential areas, while sites with a black marker were dismissed during the review.

Following the general discussion, Dr. Laferriere presented on each site's TNC scoring in the following categories: site suitability, ease of permitting, socially acceptable, eelgrass recovery area, and learning potential. Participants scored the same criteria and gave a recommendation of high, medium, or low for restoration on a worksheet. Staff and participants discussed the results. All worksheets were collected and analyzed to feed into the site suitability criteria and preferred options outlined in results below.

Science Café's:

Science cafes focused on three main topics: restoration techniques, learning potential, and other approaches. Participants choose two out of three cafes to participate in. The cafes were 30 min in length and then participants rotated into their second choice. The note taker and facilitator did not rotate, to better capture the two sessions of the cafe on that topic. The main takeaways per café are outlined below:

Restoration Techniques

- Is predation an issue for SOS? Research whether larger oysters and gear would be more beneficial.
- What is the permanency of materials we use for restoration? Ex. large granite slab for reef construction.
- How can we engage with our oyster farmers throughout the restoration process to improve our techniques and results?
- How can we continue to improve our techniques for restoration? What experiments need to be conducted?

Learning Potential

- What is the restoration synergy between oysters and eelgrass?
- What ecosystem services are provided by oyster farms and restoration? How can we quantify these values?
- How should we provide outreach and education for the public on oyster restoration? What are the best techniques?
- We need to answer the many questions concerning oyster spawning, productivity, recruitment and spat survival.

Other Opportunities

- What are the opportunities and benefits of dredging?
- What are the opportunities and benefits for multi-habitat restoration?
- What are the issues that we need to be addressing with our restoration work? Ex. substrate, predation, oyster survival
- What are the solutions to those issues? Ex. bigger oysters, floating upwellers
- Again, how can we partner with our growers throughout the restoration process?

The stakeholders were pleased to be involved in the process of both site selection and the discussion around restoration methods, learning opportunities and other approaches. Stakeholders strongly encouraged TNC to have further public engagement through electronic communications, one-on-one conversations, and small group meetings to address additional questions and concerns as a follow up to the workshop.

Workshop Site Selection Results

Results are laid out in order of highest to lowest recommendation by stakeholders.

Nannie Island:

Category	Attributes	Score
Site Suitability	• Native reef, produces very little natural spat • Bathymetry mapped & monitored • Low ice • Good Access for barges • Potential high predation	3.5
Permittable	• Not in aquaculture zone • No eelgrass currently • No standing structures • Closed to harvest*	4
Eelgrass Recovery Area	• Perhaps in the distant future	3
Socially Acceptable	• Permitted in the past • Out of aquaculture zone • Recreational oyster harvest area +/-	3
Learning Potential	• Eelgrass nearby or oysters could assist in regeneration	2

Although there was not enough time to formally evaluate and rank at the workshop, some feedback and suggestions were acquired and recorded. Nannie island was recommended highly as a restoration site due to its placement between the Nannie Native Reef and the Woodman point native reef. It was suggested that this site has great learning potential, has a large historic data set, and is well placed out of the channel and not in the Aquaculture zone.

Figure 27: TNC scoring of Nannie Island attributes in site suitability, permittable, eelgrass recovery area, socially acceptable, learning potential that was presented to the stakeholders for discussion and individual scoring.

Squamscott:

Category	Attributes	Score
Site Suitability	• Native reef, produces natural spat • Bathymetry mapped & monitored • Water quality improvement needed • Ice • Shallow for barges	3.5
Permittable	• Not in aquaculture zone • No eelgrass • No standing structures	4
Eelgrass Recovery Area	• Unlikely perhaps in the distant future	3.5
Socially Acceptable	• Permitted in the past • Out of aquaculture zone • Potential boating conflict	3
Learning Potential	• Low due to eelgrass present • Space	2

Although there was not enough time to formally evaluate and rank this site at the workshop, some feedback and suggestions were acquired and recorded on the day of the workshop. Squamscott was recommended highly as a restoration site as its placement is adjacent to the Squamscott native reef. Also, the water quality is poor in the area demonstrating a need for restoration. Fish and Game has a long-term data set at this site, showing multiple year classes and positive recruitment.

Figure 28: TNC scoring of Squamscott attributes in site suitability, permittable, eelgrass recovery area, socially acceptable, learning potential that was presented to the stakeholders for discussion and individual scoring.

Woodman Point:

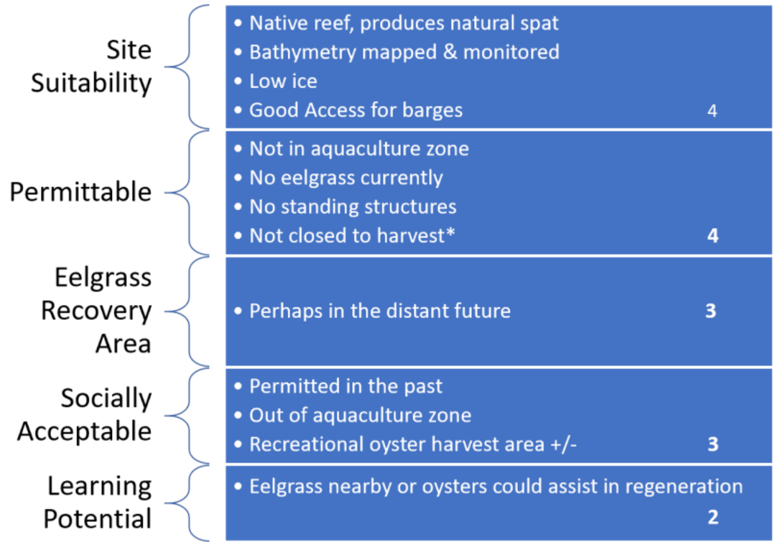


Figure 29: TNC scoring of Woodman Point attributes in site suitability, permittable, eelgrass recovery area, socially acceptable, learning potential that was presented to the stakeholders for discussion and individual scoring.

The stakeholders discussed that this site may have a conflict with recreational harvesters, as it is one of two recreational oyster sites within the system. The stakeholders also discussed the potential conflict with eelgrass restoration but also strongly suggested that this site could be an excellent learning opportunity to examine in situ eelgrass and oyster restoration synergy. There was recognition that there is a long-term data set from the native reef (NHF&G, 2019) and this could be a great area to examine larval and recruitment dynamics. The overall recommendation for this site was high.

Adams Point/Footman Islands:

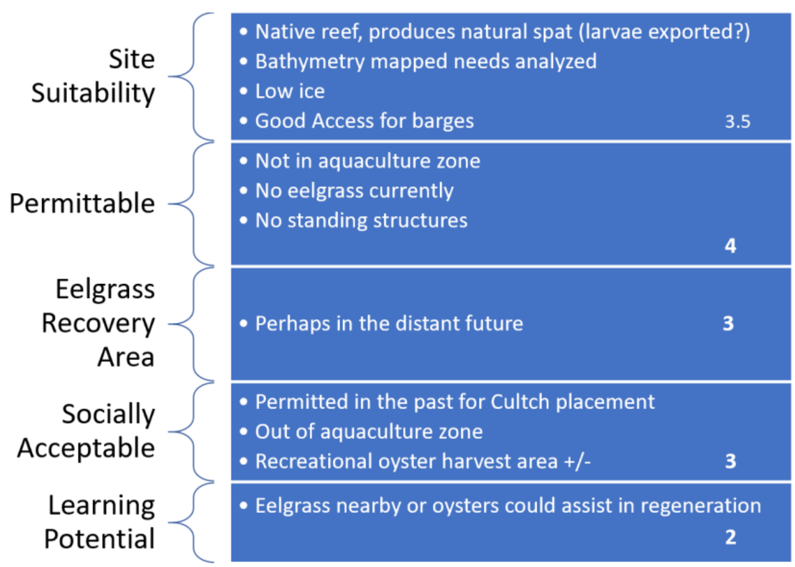


Figure 30: TNC scoring of Adams Point and Footman Islands attributes in site suitability, permittable, eelgrass recovery area, socially acceptable, learning potential that was presented to the stakeholders for discussion and individual scoring.

The stakeholders pointed out that this would be better evaluated as two separate areas. There were concerns that this site may not be ideal for restoration given the greater depth of the site, the potential of essential fish habitat for sturgeon and the potential of an eelgrass recovery area. This site would be a good area for research on the use of floating gear, alternative substrate materials such as reef balls, eelgrass and oyster synergy experiments. The overall recommendation for this site was high for Adams point and medium for the Footman Island.

Lamprey:

Site Suitability	• Native reef, produces natural spat • Bathymetry mapped & monitored • Water quality improvement needed • Ice • Shallow for barges	3.5
Permittable	• Not in aquaculture zone • No eelgrass • No standing structures	4
Eelgrass Recovery Area	• Unlikely perhaps in the distant future	3.5
Socially Acceptable	• Permitted in the past • Out of aquaculture zone • Potential boating conflict	3
Learning Potential	• Low due to eelgrass presence • Space	2

Figure 31: TNC scoring for Lamprey area of attributes in site suitability, permittable, eelgrass recovery area, socially acceptable, learning potential that was presented to the stakeholders for discussion and individual scoring.

Stakeholders were concerned about the sediment dynamics, ice floe and the amount of macroalgae at this site and thought it may impede restoration success. There were also concerns about permitting with NMFS or ACOE, access for barges to deploy shell due to shallow water. There were suggestions that this area would be a good site for research on quantification of water quality improvement before and after the upgrade to the Newmarket WWTF and investigation of the effects of ice on oyster population dynamics. The stakeholders strongly encouraged working closely with land abutters. There was recognition that the native reef at the Lamprey was in good condition with a productive reef base and recruitment the last several years. The cumulative recommendation from the stakeholders was medium to high.

Oyster River:

Site Suitability	• Native reef, produces some spat • No mapped, very soft sediment • Water quality improvement needed • Ice • Shallow for barges	3
Permittable	• Not in current aquaculture zone, could be... • No current eelgrass • No standing structures	3
Eelgrass Recovery Area	• High priority for eelgrass recovery	1
Socially Acceptable	• Permitted in the past • Potential aquaculture conflict • Potential boating conflict	2
Learning Potential	• Good for learning about synergies with oysters & eelgrass	3

Figure 32: TNC scoring of Oyster river attributes in site suitability, permittable, eelgrass recovery area, socially acceptable, learning potential that was presented to the stakeholders for discussion and individual scoring.

The stakeholders discussed the potential of removing the dam and how common flooding events could affect the restoration efforts. There was a discussion if abutters would be supportive of restoration in the waterway. There was a strong suggestion to move further upriver to avoid future aquaculture expansion. The stakeholders discussed the potential conflict with eelgrass restoration and strongly suggested that this site could be an excellent learning opportunity to examine in situ eelgrass and oyster restoration synergy. The overall suggestion was variable to medium for this site, mainly based on future activities such as dam removal and aquaculture expansion.

Three Rivers/Piscataqua:

Site Suitability	• Native reef, produces natural spat, might be growing • Not mapped • Water quality improvement needed • Ice • Shallow for barges	3
Permittable	• Not in aquaculture zone • No eelgrass • ME border • No standing structures	3.5
Eelgrass Recovery Area	• Unlikely perhaps in the distant future	**3.5**
Socially Acceptable	• Permitted in the past • Out of aquaculture zone • Potential boating conflict	**3**
Learning Potential	• Low due to eelgrass presence • Space	**2**

Figure 33: TNC scoring of three rivers/Piscataqua attributes in site suitability, permittable, eelgrass recovery area, socially acceptable, learning potential that was presented to the stakeholders for discussion and individual scoring.

The stakeholders discussed that this site may be challenging to conduct restoration because of strong currents and scour in the channel. Given that the site is on state lines, permitting may be more complicated and if it was cross cutting across state boundaries it may pose a navigation hazard. This may be a site that could be used to learn about the eelgrass and oyster restoration synergies and may be useful to use alternative methods such as reef balls. Historically this site has had outbreaks of MSX and vibrio. It was noted that it would be beneficial to have a site outside of GB and work across state boundaries. The overall recommendation of this site was medium to low.

Conclusion
The stakeholder engagement process was highly effective in soliciting information and feedback on site selection, restoration techniques and stakeholder engagement. The Lamprey, Squamscott, Nannie Island, Woodman Point and Adams point were all highly recommend as potential future restoration sites. Future restoration at the Oyster River will be dependent on whether the dam is removed. The Piscataqua/Three Rivers site was not recommended for a variety of factors including ease of work. Several different areas were identified for researching the synergy of eelgrass and oyster restoration, ice floe, and the effects of oyster restoration on water quality.

The stakeholders' input and feedback that oyster growers should be more involved in restoration techniques and processes was greatly developed and expanded into a working partnership and collaboration between TNC and NH oyster growers. The partnership included **multiple** oyster growers growing SOS and seed in summers 2019 and 2020 and the purchase of "Uglies" (adult oysters that cannot go to market) that were deployed on the restoration site as a pilot to advance oyster filtration and reproduction.

IV. Site Suitability Criteria and Recommendations
2019 and 2020 Oyster Restoration Efforts
Restoration efforts, raising oysters and working with oyster farmers continued in 2019 and 2020 to further inform and test strategies for Restoration by Design. 250 cubic yards of clam shell was deployed at the existing Woodman Point site to further build out the restoration area. The Woodman Point site showed great promise from monitoring in 2019 (Grizzle & Ward, 2020a). In 2019 and 2020 we reared SOS at the Jackson Laboratory and worked with oyster growers to grow SOS, seed and trialed alternative substrates. Approximately 1.5 million oysters were reared in 2019-2020 with an additional estimated 59,455 oyster spat in 2020 from the OC Program. We do not have OC survival data from 2019 due to a settlement failure.

In 2019, through conversations with growers we started a pilot scale project to purchase and deploy "uglies" or surplus oysters that cannot go to market, but have conservation value of filtering water, reproducing and providing habitat. Our results from this pilot study yielded a 71% survival rate, growth on a subset of oysters and recruitment of conspecifics (Laferriere & Group, 2020). When the global pandemic hit in March of 2020 it effectively shuttered restaurants and closed the oyster half shell market. This "Uglie" pilot scale study was the backbone for the National TNC SOAR (Supporting Oyster Aquaculture and Restoration) project. SOAR was designed to assist oyster farmers impacted by COVID-19 and the resulting economic downturn by purchasing surplus oysters and placing them on nearby oyster restoration projects—a win-win for the shellfish industry and the environment. SOAR was implemented in 7 states; in NH we deployed 312,000 adult oysters onto a 1-acre site on the restoration site at Nannie Island.

In addition to the collaborative work between TNC and Dr. Grizzle and Ms. Ward of UNH, there has been substantial reef restoration funded by the Natural Resources Conservation Service (NRCS) conducted by Dr. Grizzle and Ms. Ward as oyster farmers and consultants. In developing recommendations for Restoration by Design, we were informed by an evaluation of NRCS-funded oyster restoration sites in the Great Bay Estuary undertaken by Dr. Grizzle and Ms. Ward in 2019 (Grizzle & Ward, 2020b).

Eelgrass: State of the Science

Eelgrass (*Zostera marina L*) is an important habitat in the Great Bay-Piscataqua Estuary that provides essential ecosystem services such as providing nursery habitat for fish and invertebrates, vast amounts of oxygen production, nitrogen removal from the water column thereby improving water quality and sediment stabilization (Thayer et al. 1984, Sandoval-Gil et al. 2016, Heck, 2019, Burdick et al.2020). Since the 1990s there has been significant loss of eelgrass beds, with an approximate 44% reduction in acreage since 1996 due to point and non-point source pollution resulting in highly degraded water quality (Short 2016, Burdick et al. 2020). However, in recent years there has been a push for significant upgrades in wastewater treatment facilities (WWTF) which has reduced nitrogen loading and could lead to improved water quality potentially developing enabling conditions for eelgrass recovery (Burdick, 2020).

Eelgrass was recognized as an important habitat and was highly considered by stakeholders and TNC when scoring restoration sites. The 2018 "Restoration by Design" stakeholder workshop catalyzed a group of local academics and managers to come together in 2019 to develop a "case for restoration and recovery" for eelgrass to better understand if the system was ready for eelgrass recovery (Burdick et al. 2020). This state of the science paper outlines historical and current eelgrass density and distribution, local stressors, data that will update a site selection model and restoration methodologies.

Since the publication of the state of the science in early 2020, a team of scientists and managers have formed and developed a pilot scale restoration project that will be implemented in summer of 2021. This group is encouraged by recent data that found eelgrass had increased by 8.5% from 2017-2019 and that beds were taller and denser (Matso et al., 2020). Oysters and eelgrass have both been able to thrive in the Great Bay system in the past. Given our goals of balancing future oyster restoration with eelgrass recovery, potential eelgrass restoration sites were highly considered by TNC staff as a criteria when designing future oyster restoration sites. Furthermore, there are sites in the estuary that are suitable for experimentation on the synergies of eelgrass and oyster restoration and are noted in the recommendations.

Larval and Recruitment Research

From 2018-2020, TNC conducted a recruitment study at five native and restored reef sites alongside a larval study conducted by Dr. Dijkstra at UNH. Our methodology changed from 2018-2019. The five sites included Lamprey, Squamscott, Woodman Point, Nannie Island, and Nannie Island restored.

In 2018, a high number of spat recruited to the Nannie Island restored reef device with 20-104 spat per tile (Figure 34 and 35), with very few recruiting to the Nannie Island Native and Squamscott River (Lamprey device was lost) (Harper et al.,2018). In 2019, we deployed recruitment devices at the Lamprey, Nannie Island Native, Nannie Island Restored, Squamscott, Woodman Point, and Adams Point. Only four spat settled on the recruitment device at the Lamprey River site (Laferriere and Group, 2019. In 2020, we saw few spat settled on the Nannie Island native and Woodman Point devices (1 spat per device). Similar to 2018 we lost the Lamprey device and saw a high number of recruited spat to the Squamscott River device (4-11 spat per tile) (Laferriere and Group, 2020). This number was higher than in 2019, but lower than the spat recruited in 2020. We hope to continue deploying recruitment devices at these sites to develop a long-term dataset for evaluating oyster recruitment at the native reefs.

Figure 34. A tile used in the 2018 recruitment study taken from Nannie Island restored site covered in oyster spat.

Alongside the recruitment study, a larval study was conducted in 2018-2019 led by Dr. Dijkstra at UNH. Students examined the abundance of oyster larvae and peak spawning times throughout the summer months in the GBE by towing at 4 sites once a week. Results from this study found that the Squamscott yielded the most larvae and Nannie Island the least in 2018 (Dijkstra & Bumbera, personal communication). In addition, it was found that oyster spawning peaked on July 24th with a second peak on August 20th (Dijkstra & Bumbera, personal communication). In 2019, this study found that Nannie Island yielded the most larvae and Woodman Point the least, spawning peaked in early August (Dijkstra & Bumbera, personal communication).

Figure 35. Recruitment device used in 2019 and 2020. Each device contains 4 tiles and is held in place with bricks and attached to a buoy.

Native Oyster Reefs 2020

A critical aspect to further identify and define areas for future restoration was to map the spatial extent and condition of the native oyster reefs. TNC contracted with Dr. Grizzle and Ms. Ward of the Jackson Estuarine Laboratory in summer of 2020 to conduct the survey which resulted in a spatial database and clear understanding of reef condition (Figure 1, Section I). Field assessment was conducted via underwater video and tong sampling at six major natural reefs: Adams Point, Nannie Island, Woodman Point, Squamscott, Lamprey and Oyster River. The mapping also included most of the adjacent restored reef areas in the Squamscott and Lamprey Rivers. *The video imagery was classified into three major categories: "non-reef" (sparse or no shell cover, no live oysters visible), "reef" (20 to 50% shell cover and potentially [based on video imagery] live oysters), and "dense live reef" (>50% shell cover and potentially [based on video imagery] live oysters) (Grizzle & Ward, 2020c).*

Handheld and patent tongs were used to sample the natural reefs to assess spatial variability in reef condition. Oysters were binned into four categories: *no live oysters, low density (<5 oysters/m^2), medium density (~5 - 50 oysters/m^2), and high density (>50 oysters/m^2)*(Grizzle &Ward, 2020). *All live oysters collected were counted and measured (shell height to nearest mm) with a ruler. Notes were recorded on condition of dead shells, sediment buildup, and other features relevant to overall reef condition, and other live bivalves were noted* (Grizzle & Ward, 2020c).

The Lamprey and Squamscott reefs had the highest densities of live oysters including multiple age classes with a spat set in 2020 (Table 7, Grizzle & Ward, 2020c). Adams Point and the Oyster River had low density of live oysters. Woodman Point and Nannie Island had low densities or no oysters and highly degraded reefs (Table 7). The author notes that reefs with high oyster densities are in closed waters whereas the highly degraded reefs are in harvestable waters and suggest the recreational harvest of oysters has adversely affected the condition of the reefs. The survey also observed that the shell on degraded reefs was in bad condition and may offer poor substrate for larval settlement (Grizzle & Ward, 2020c).Results of the spatial extent of mapping in 2020 showed a total of 78.8 acres compared to 72.8 acres mapped in 2012 (Grizzle & Ward, 2013, Grizzle & Ward, 2020c). These results show a slight increase in native oyster reefs and note that a small acreage can be attributed the restoration areas mapped in the Squamscott. It should be noted that comparison of native reef maps over time since 1997 show large temporal variability in part due to method, shifting sediments and advancing technology (Lippmann, 2018, Grizzle & Ward, 2020b).

Table 7. Modified from Grizzle & Ward, 2020c. Summary data for live oysters and other bivalves collected from natural oyster reefs in 2020 mainly with handheld tongs; patent tongs were used for some samples at Adams Point, Woodman Point, and Nannie Island.

Reef Name	Date Sampled	Total # Tong Replicate	Tong Replicate	Waypoint	<40 mm	40-59 mm	60-79 mm	>79 mm	Total # Live Oysters/Tong	Notes
Adams Point	9/9/20 9/23/20	28	6	952			1	1	2	Live oysters in 1 of 28 replicate samples; badly degraded oyster shells and heavy mud buildup in most samples; a total of three live hard clams collected
Lamprey River	9/16/20	9	3	1117	2	3	5	10	20	Live oysters in 5 of 9 replicates; ribbed mussels found in 2 samples
			4	1118						
			7	1121						
			8	1122						
			9	1123						
Oyster River	9/15/20	19	4	1014				2	2	Live oysters in 10 of 19 replicate samples; ribbed mussels or blue mussels found in 3 samples
			5	1015				2	2	
			6	1017			1	1	2	
			7	1018		1	1	3	5	
			8	1019			2		2	
			9	1020			1		1	
			10	1021		1	1	5	7	
			13	1024				1	1	
			14	1025			1	4	5	
			15	1026			1	2	3	
Woodman Point	9/14/20	32	2	973	1				1	Live oysters in 32 replicate samples; badly degraded oyster shells and heavy mud buildup in most samples, total of 7 live hard clams collected
			10	982				1	1	
			12	986				1	1	
			23	999				2	2	
			27	1004				1	1	
			32	1035				1	1	
Nannie Island	9/14/20	9								No live oysters collected; one live hard clam collect; badly degraded oyster shells and heavy mud buildup in most samples
Squamscott River	9/16/20	26	6	1089				1	1	Live oysters in 6 of 26 replicate samples; ribbed mussels (>10 in one sample) in four of six samples; surface impenetrable in some areas, completely covered by oysters
			17	1100			1	4	5	
			19	1102	3	4	1	2	10	
			21	1108		2	10	3	15	
			22	1110		2	4	8	14	
			23	1111		2	3	6	11	

Site Suitability Criteria

When developing a set of site suitability criteria and methodologies for Restoration by Design, we conducted a synthesis and integration of historical and current data on spatial extent, condition and abundance at native oyster reefs (Grizzle & Ward, 2013,2020b,c, NHFG, 2019), shell persistence, and oyster survival at restoration sites (Grizzle & Ward, 2016, 2018,2019, Lippmann 2019). We augmented our database with spatial layers from bathymetric mapping and sediment change maps to inform sediment dynamics (Lippmann, 2019), eelgrass maps and expert opinion (personal communication, Fred Short, Matso et al. 2020), water quality and shellfish management areas (NHDES, 2019), and research results from larval and recruitment studies (Dijkstra,2018, Laferriere & Group, 2020). We then enhanced our criteria list with social layers, such as permitting requirements, social interests, and aquaculture lease areas (historical and projected) to generate a suite of criteria. We strove for creating recommendations that balance future oyster restoration with eelgrass recovery and social interests. This was a multifaceted approach of social and ecological consideration that were all considered when designing and recommending sites and methodologies for future restoration. All our site suitability analysis was completed considering The Nature Conservancy's conservation goals: improve water quality and provide habitat by conducting oyster restoration within the system. A list of site suitability criteria is outline in Table 8 below.

As noted in the stakeholder engagement section, three sites were removed from the options during technical review. Great Bay and South of Adams Point were removed due to poor sediment dynamics, resulting in shell piles being buried in the past. We were thankful and reliant on the long-term dataset that the New Hampshire Department of Fish and Game (NHFG) has collected at the Squamscott River, Woodman Point, Adams Point, Oyster River, Nannie Island, and Piscataqua River sites where they assessed oyster density and size distribution every year since 1993 (NH Fish and Game, 2019). We also removed the Bellamy River site due to the dam removal in 2019. The dam on the Oyster River may also be removed, therefore our recommendations follow a decision tree based on whether it is removed or not. As mentioned above the eelgrass working group is well underway and about to launch into pilot restoration of eelgrass in GBE in summer of 2021. These current events, including the deployment of adult oysters were considered when designing our site and methodology recommendations for Restoration by Design.

Table 8: Site suitability criteria considered in the analysis for future oyster restoration sites and methodologies.

Criteria	Source
Proximity to native reef	Grizzle & Ward, 2016, 2020 b, c, Atwood & Grizzle, 2020
Native reef spatial extent & condition	Grizzle & Ward, 2013, 2020 b, c
Oyster abundance at native reef (includes age classes)	Grizzle & Ward, 2020, NHFG, 2019
Larval and recruitment dynamics	Atwood, & Grizzle, 2020, Dijkstra and Bumbera, unpublished data, 2019 Laferriere & Group, unpublished data, 2020
Historical restoration cultch persistence	Grizzle & Ward, 2016, Grizzle & Ward, 2020 b, c
Historical restoration oyster survival	Grizzle & Ward, 2016, 2019, 2020b
Sedimentation, sediment dynamics	Lippmann, 2016, 2019
Eelgrass areas: historical, current, recovery areas, potential restoration sites	Fred Short, personal communication, Burdick et al., 2020, Matso et al., 2020
Water classification shellfish management areas	NHDES
Aquaculture areas	NHFG, NHDES
Permittable	ACOE, NMFS, NHDES
Logistical considerations	Laferriere & Group, Riverside and Pickering
Social interests	Personal communication, 2018 workshop
Current or projected hydrodynamic changes (i.e., dam removal)	NHDES, town of Dover, town of Durham
Stock enhancement	TNC, SOAR

Recommendations

We describe potential restoration sites based on site suitability criteria (Table 9) and prioritized sites for restoration success as low, medium or high. We grouped our site recommendations by two restoration design methods:

1) Placement of cultch or shell on bottom to provide substrate near healthy reefs to enable the successful recruitment to the reef base.

2) The deployment of SOS or reproductive adults on existing cultch to enhance stock and reproductive success of native populations.

We also recommend specific sites for a focus on multihabitat, oyster and eelgrass restoration approach, and utilizing oysters via restorative aquaculture or poly restoration. We include recommendations for temporary closures to recreational harvest at specific sites to allow the native populations to rebound to a more natural state (Figure 36). Each site is unique in its attributes and method of scoring to the criteria; therefore, each design is site specific, often multiple methods will need to be employed to achieve restoration success.

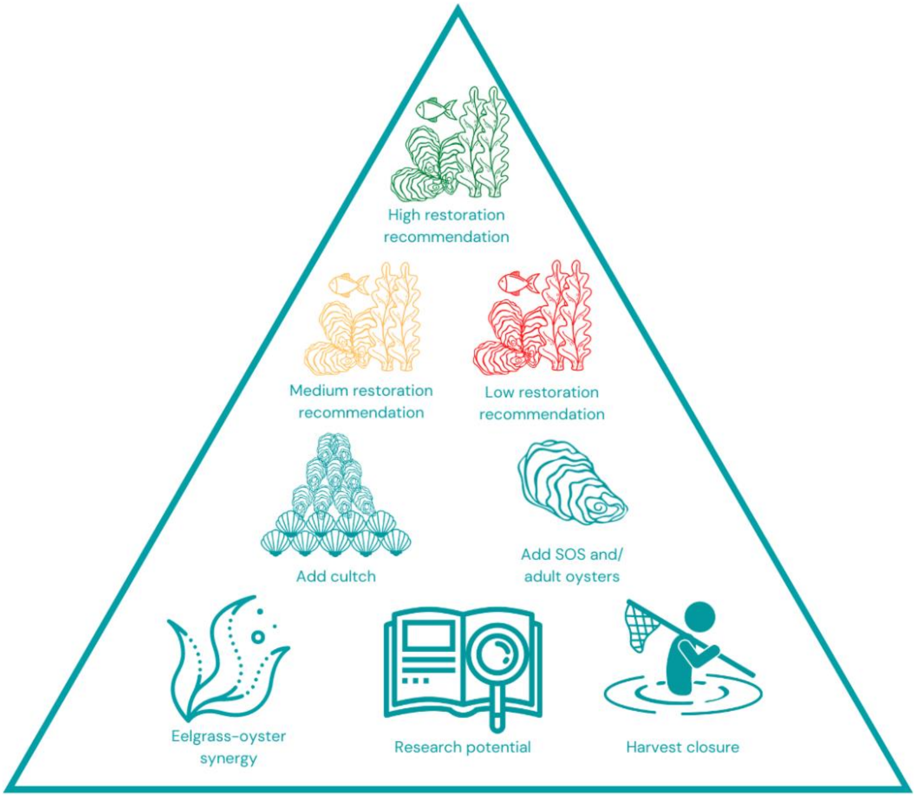


Figure 36. Restoration recommendation key. These images are used to illustrate the overall recommendation and suggested techniques at each site based on the site suitability criteria.

Cultch Placement/Reef Base:

Adams Point

We prioritized this site as medium-low for future restoration. There was low density of oysters (2-11 per tong) at the nearby native reef and the reef was observed to have heavy sedimentation during field assessment (Grizzle & Ward, 2020 b,c.). The NHFG data set shows that although there are adult oysters at this site, the adults were at low densities in 2018 at 1.2 per 0.25m^2 and recruitment was 0 in the 2018 field survey. The last positive recruitment event appears to be in 2015 (16.8 per 0.25m^2) and 2013 (28.4 per 0.25m^2) (NHF&G, 2019). Based on this data and other observations this native reef appears to be in dramatic decline and not reproductive. TNC's recruitment devices have not collected recruitment at this site in the summers of 2018, 2019 and 2020. This area is open to recreational harvest with significant pressure (personal communication, JEL staff) and has been noted to have an intertidal population (personal observation).

Reef restoration conducted by Dr. Grizzle and Ms. Ward at Adams Point yielded some persistence in cultch placement. Bathymetric surveys conducted by Dr. Tom Lippman (Center for Coastal & Ocean Mapping, UNH) on July 03, 2019 produced profiling of the site where water depths range from ~2 m along the western edge and up to 11 m on the eastern side (Lippmann, 2019). Given the deep-water depth it has good access for barges and high flow. Given its proximity to JEL and depth, this site would be a good area for research on the use of floating gear and alternative substrate materials such as reef balls. Given the limited productivity of this site, and that the site is still open to harvest we recommend a short-term closure at this site with the addition of adult reproductive oysters to enable the population to rebound. Following the closure and addition of adults, we recommend the addition of cultch in the TNC recommended site which extends between the native reef and the 4-acre permitted site (Grizzle & Ward, 2020b) (Figure 37). The recommended TNC polygon is 2.6 acres in size. This area was covered in native oyster reef during the 2013 mapping update, and data from the 2020 mapping update shows this area of reef has been lost (Grizzle and Ward, 2013, 2020c). It should be noted that although the reef has contracted in this area, it has expanded on the eastern portion. We support the deployment of cultch (where needed) on the existing 4-acre permitted site (held by Dr. Grizzle and Ms. Ward).

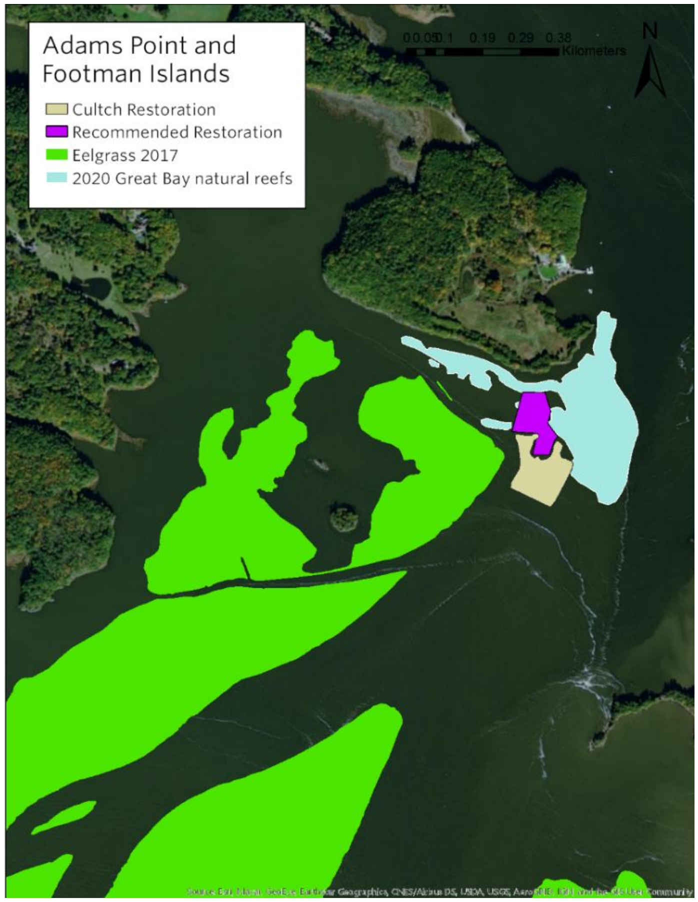
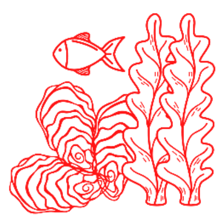


Figure 37. Proposed site (purple) for addition of cultch to the Adams Point site extending the native reef (blue) and the cultch restoration work by Dr. Grizzle and Ms. Ward (tan).

Footman Islands



We prioritized this site as low for restoration but with an eye towards the future. It was noted in the stakeholder engagement section that this site should be analyzed separately from Adams Point. Although this site is in shallow water with less current it also is farther from the native reef, therefore deployment of cultch would not likely be good substrate for natural spat (Figure 37). According to the 2017 eelgrass mapping this area may be a site for future eelgrass recovery. This area should be monitored for eelgrass recovery and should be reconsidered based on Adams Point native bed population dynamics and associated restoration area success or failure.

Lamprey

We prioritized this site as low for future restoration. The native reef is relatively small (0.6 acres), has a high density of oysters (453 per tong), and was observed to be in good condition (Grizzle & Ward, 2020c). However, this site poses challenges to successful restoration. The area experiences heavy sedimentation, a soft mud bottom (Lippmann, 2019, Grizzle & Ward 2020b), and a narrow channel which makes it difficult for barges to access and poses a conflict with boaters (Figure 38). Given the high production of the native reef, several TNC/UNH collaborative restoration sites and NRCS funded sites have been placed in the Lamprey River (Grizzle & Ward, 2016, Grizzle & Ward, 2020 b, c). The restoration sites have been fairly successful with shell intact and natural recruitment of multiple year classes. However, the US Army Corps of Engineers (USACE) “maintained” navigation channel will not allow any additional shell deployed at this site, leaving little room for future restoration. Given these logistical and permitting constraints, we do not recommend the placement of cultch or oysters at this site. This is a good site for future research to ascertain if and to what extent the native reef merges with existing restoration sites. There were suggestions from stakeholders that this area would be a good site for research on quantification of water quality improvement before and after the upgrade to the Newmarket WWTF as the reef naturally develops and expands.

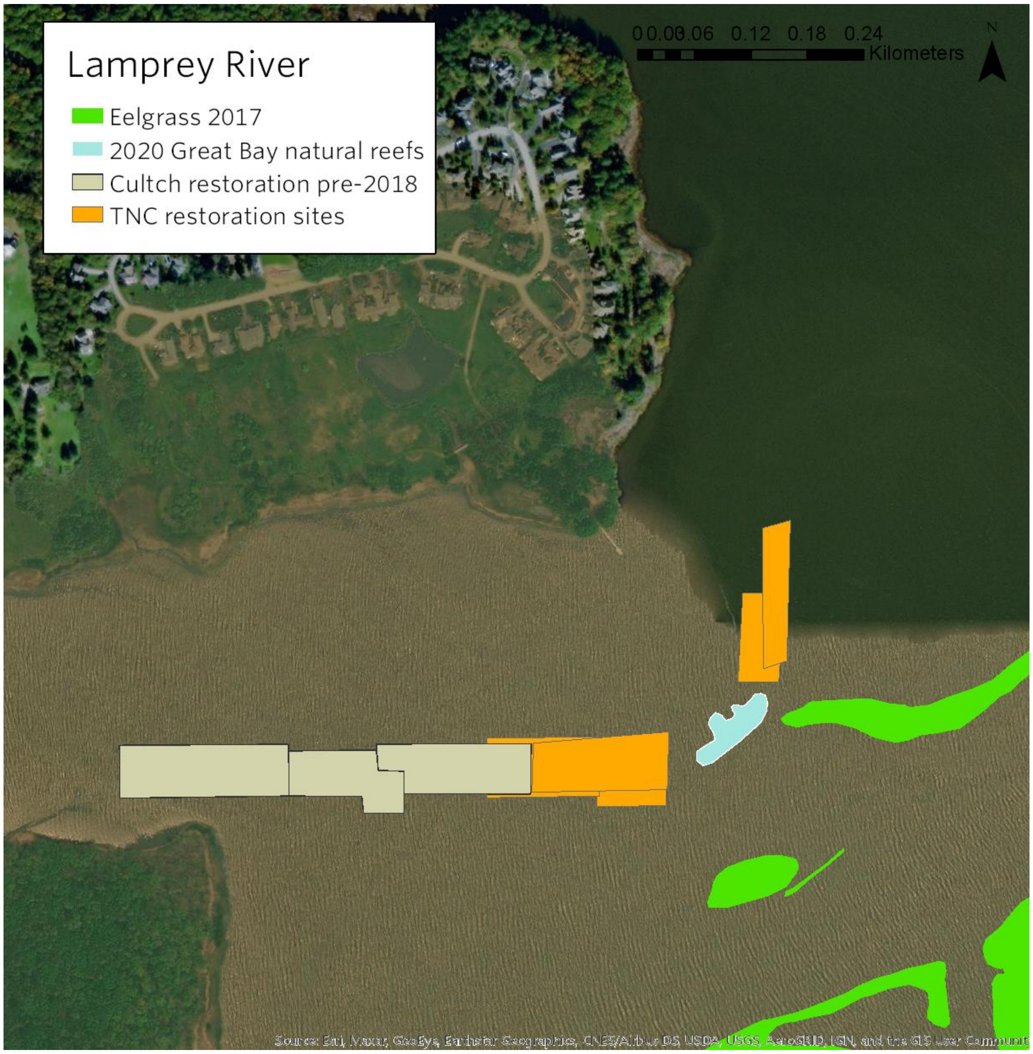


Figure 38. Lamprey River restoration sites including TNC (orange) and cultch restoration (tan) surrounding the productive native reef (blue). Future restoration at this site is not recommended due to a space limitation. However, the native reef is healthy and productive and a great site for future research.

Oyster River

We prioritized this as low-medium in the near term, due to the potential pending dam removal and medium if the dam is not removed or after a period of monitoring flow and sediment dynamics at this site. Restoration was conducted at this site in 2009 and there is some persistence of shell. Live oysters were found on the native reef in 2020 and the native reef was shown to expand in size from 1.4 acres in 2012 to 3.5 acres in 2020 (Grizzle & Ward, 2020c). NHF&G yearly survey shows that oyster densities are at relatively high levels at 25.4 per $0.25m^2$ (Fish and Game, 2019). The stakeholders noted a concern of abutters and the narrow channel at this site. In January of 2020, the leased area for oyster aquaculture was increased northwest into the river, potentially constricting the area for restoration. However, it is critical to note that both wild and farmed oysters provide similar ecosystem benefits and **we support restorative oyster aquaculture.** Oyster farming in the Oyster River would improve water quality because those oysters are filtering water, removing nitrogen from the water and are terminally removing nitrogen from the system through harvest. We propose that future restoration within the Oyster River is north and west of the aquaculture lease area and nearby the native reef. We have recommended a future restoration site that juxtaposed the native reef in an area that encompasses 2.6 acres (Figure 39). We suggest the lower portion of the river could be allocated for future shellfish aquaculture expansion. It should be noted, this site could be used for experimentation and an excellent learning opportunity to examine in situ eelgrass and oyster restoration synergy.

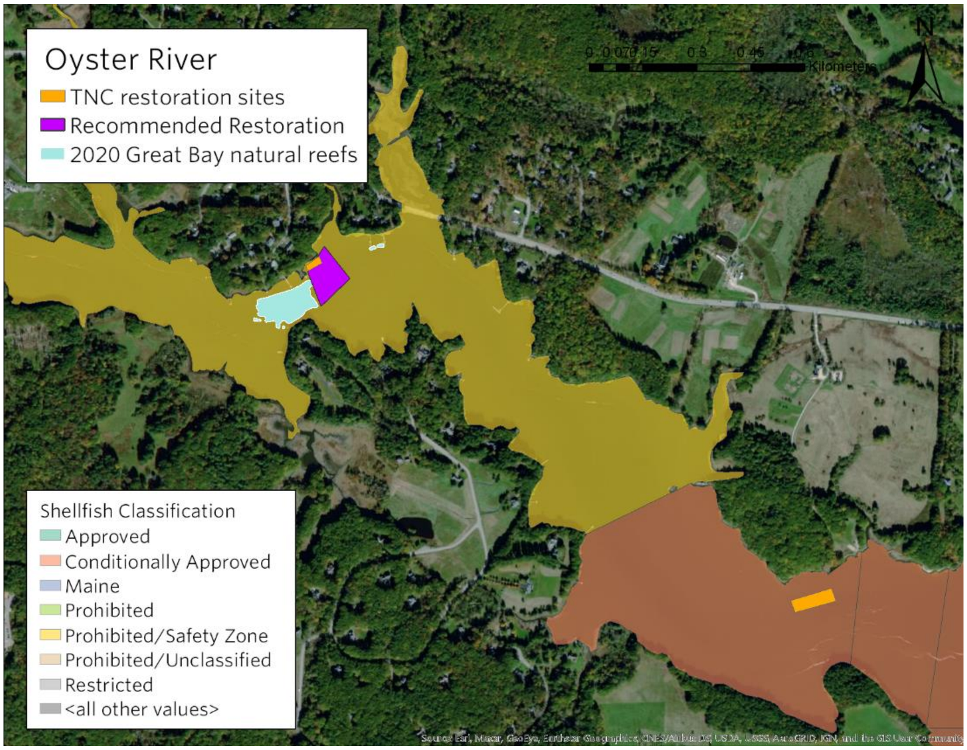


Figure 39. Proposed restoration site in the Oyster River (purple) next to previous TNC restoration site (orange) and the productive native reef (blue). It is important to note that the site proposed falls in the Prohibited/Safety Zone of the Shellfish Classification (yellow) so as not to conflict with aquaculture leases in the Conditionally Approved zone (orange).

Piscataqua River

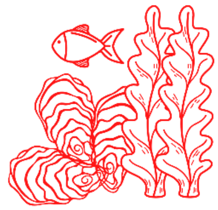
We prioritized this site as medium for pure oyster restoration and high for future investigation. Unfortunately, due to Covid-19 restraints Grizzle and Ward were not able to sample the Piscataqua in the 2020 oyster mapping update produced for TNC. Therefore, the reef extent or condition has not been assessed since 2012 (Grizzle & Ward, 2013). NHF&G data set from surveying in the northern section of the Piscataqua reef shows that there are multiple year classes of oysters at this site, 49 oysters per 0.25m^2 were found, with a third of the oysters in the 0-20mm year class indicating this reef is productive and recruiting (NHF&G, 2019). Reef restoration has been conducted by TNC at this site in 2013, where 150 yards of shell was deposited on the 1.5-acre site (Figure 40). The area of shell cover was 54% when first deployed and persisted at 23% area covered when surveyed in 2016 (Grizzle & Ward, 2016). With a productive reef, that is thought to be expanding in size and proven restoration in the past, this is a good site to strongly consider for future restoration.

However, this site does pose logistical challenges to large scale restoration; strong currents, scouring of the channel, difficult for barges to access and maneuver. Given that the site is on state lines, permitting may be more complicated and if it was cross cutting across state boundaries it may pose a navigation hazard. This may be a good location to examine the synergies and challenges of eelgrass and oyster restoration and potentially do a poly restoration, or combination of oyster restorative aquaculture approach with a complimentary eelgrass planting. Although oyster restoration at this site would not improve water quality in Great Bay, it would improve water quality in the Piscataqua which is greatly impaired.

Grizzle and Ward (2020c) have identified 8.5 acres of potential restoration area in the Piscataqua. We highly recommend that prior to conducting restoration, the area needs to be mapped to determine the full and current spatial extent of the native reef. Once the area is mapped and reef condition assessed, polygons can be drawn to identify the best areas for restoration. Given these parameters, once mapping is complete, we recommend placing cultch on bottom to provide substrate for the productive native reef and to collaborate with Dr. Grizzle and Ms. Ward on future restoration. We also suggest monitoring water quality and eelgrass recovery in this waterway and TNC plans to keep in close communication with the eelgrass working group on potential experimentation and poly-restoration in the southern portion of the river.

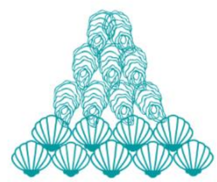
Figure 40. TNC reef restoration from 2013 (orange) shown abutting the native reef (blue). This mapping was conducted in 2013 and would need to be updated before any further restoration work was completed.

Salmon Falls River



We prioritized this site as low, given the above constraints of the Piscataqua which would be exacerbated by moving north into the river and not knowing the spatial extent or condition of the reef at this site. We are not recommending restoration at this site at this time. Fish and Game has not sampled this site since 1997 (NHF&G, 2019), if and when there is successful restoration at the Piscataqua site we recommend determining the spatial extent of the native reef within the Salmon Falls River.

Squamscott River

We prioritized this site as high for future restoration largely based on the proximity hypothesis of being successful by being nearby a productive native reef (Eckert, 2016, Atwood & Grizzle, 2020). There is a high density of oysters (222 per tong, Grizzle & Ward, 2020c) at the native reef and was observed to be "impenetrable" and completely covered in oysters during field assessments in 2020 (Grizzle & Ward, 2020c). NHF&G data set shows live adult oysters, multiple year classes and positive recruitment (NHF&G, 2019). Additionally, TNC's recruitment devices have collected recruitment at this site in multiple pulses in summers of 2018, 2019 and 2020. Reef restoration conducted by Dr. Grizzle and Ms. Ward in the Squamscott showed persistence of clutch placed on bottom, the shell was in good condition and there was natural recruitment onto the clam shell (Grizzle & Ward, 2020b). The native reef has grown from 7.7 acres in 2012 to 11.2 in 2020, although the authors point out that this may be a continuation or merging of native reef onto restoration area (Grizzle & Ward, 2020c).

Although there is a slight concern of sedimentation at this site, the data collected points to the shell being persistent. This area has been permitted in the past, and although shallow, large barges have been willing and able to navigate in this channel. This site had a high prioritization from stakeholders as it is out of the aquaculture zone, recreational harvest and is not a site for potential eelgrass recovery or restoration. This site is under permit for future restoration by Dr. Grizzle and Ms. Ward as oyster farmers and there is 9 acres of permittable area for restoration (Grizzle& Ward, 2020b). Given the productivity and positive recruitment at this site, and the high ranking given by Grizzle and Ward (2020b) NRCS funded restoration sites we concur and highly recommend only the placement of cultch in the Grizzle & Ward (2020b) recommended sites and not the deployment of SOS or adult oysters at this site (Figure 41).

Figure 41. Cultch restoration completed by Dr. Grizzle and Ms. Ward (tan) in the Squamscott River nearby native oyster reef (blue).

Deployment of Oysters (SOS & Adults)

Nannie Island:

We prioritized this site as medium-high for future oyster restoration with a sharp focus on reaching our conservation strategies' of improving water quality. Reef restoration conducted by TNC at this site in 2016 and 2017, which deployed 500 yards of clam shell as a reef base across each 5-acre site resulted in solid persistence of the clam shell piles placed at both sites (Lippmann, 2019). SOS that were deployed on this site in 2017 have had low survival over time which may be due to predation (Grizzle & Ward, 2019). The cultch that was placed on this restoration site has not caught a set of native oysters. This is likely because there have been no oysters found on the native reef and the reef is in poor condition (Grizzle & Ward, 2020 a,b). NHF&G sampling has not found any live oysters on Nannie native reef since 2016 and the area has not had a substantial positive recruitment event since 2006 (NHF&G,2019). TNC's recruitment devices did collect a natural set on the native reef in 2018 but did not at the restoration site or native reef in 2019 or 2020. The poor condition of the nearby natural reef suggests that natural recruitment would be limited to none onto the clam shell piles onto the restoration site. Therefore, we recommend the deployment of adult oysters on the two TNC existing restoration sites, which covers 10 acres and to work collaboratively with Ms. Ward on the 7-acre NRCS funded site (Figure 42).

It should be highlighted that 312,000 adult reproductive oysters by TNC's SOAR (Supporting Oyster Aquaculture and Restoration) program were deployed in a 1-acre site within the Nannie Island Restoration area in Fall of 2020. TNC will be monitoring this site for survival and growth and this site and surrounding reefs (native or restored) will be assessed for recruitment and year classes over time. This deployment of reproducing adults could act as a larval source for the surrounding reefs.

It should be underscored that the 5-acre 2017 restoration site is currently closed to recreational harvest until December of 2021. The native reef is open to recreational harvest and is the subject of consideration to have a closure. State managers recognize that the oyster densities at the Nannie Island Native Reef have declined to near zero and there is a working group (NHF&G, Dr. Grizzle and Dr. Brown of UNH and Dr. Laferriere of TNC) discussing a proposal to establish a 5-acre harvest closure area. The proposed closure will overlap with the existing TNC closure on the restoration site to protect the adult oysters deployed there in 2020 to support stock enhancement to the native reef.

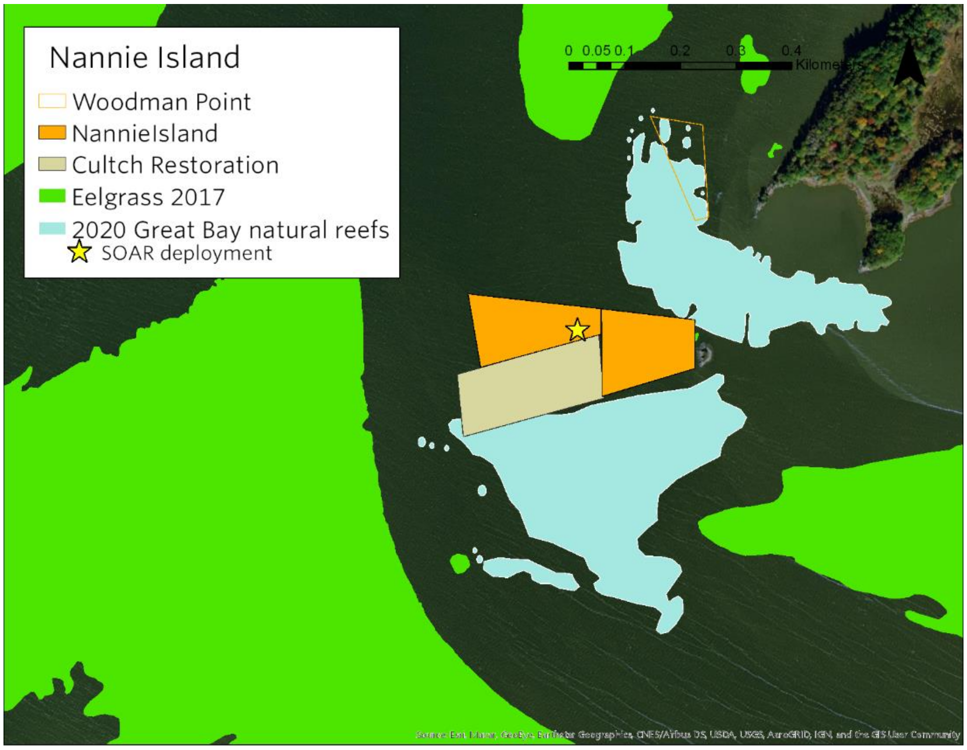


Figure 42. Recommended oyster restoration site (purple) between the Nannie island restored sites (orange), Woodman Point native reef (blue), and Woodman Point restored site (outlined in orange).

Woodman Point:

We prioritized this site as medium-high for future oyster restoration with a sharp focus on reaching our conservation strategies' of improving water quality and improving habitat. Reef restoration was conducted by TNC at this site where we deployed 540 yards of clam shell on the site over two years. Monitoring of the site in November of 2019 resulted in 60% coverage of the shell and mounds were intact (Grizzle & Ward, 2020a, Lippmann, 2019). SOS that were deployed on this site in 2018, 2019, 2020 have survived and grown over the last two years (Grizzle & Ward, 2020a). However, the cultch that was placed on this restoration site has caught only limited amounts of native set. This is likely because there are low densities of oysters at the native reef and the condition of shells on that reef are badly degraded (Grizzle & Ward, 2020a,b). NHF&G sampling of this reef has shown minimal recruitment for the past two years, and total live oyster densities averaging only ~26/m^2 (Fish and Game, 2019). TNC's recruitment devices did not collect a natural set on the restoration site or native reef in 2018, 2019 or 2020. This area is open to recreational harvest and has experienced, dramatic declines in recent years and further restoration or closure may result in conflict with harvesters.

The poor condition of the nearby natural reef suggests that natural recruitment would be limited, but the positive survival and growth of the SOS at this site lends credibility to this site for long term restoration and monitoring. We highly recommend the deployment of SOS and if a closure is implemented then deployment of adults at this site. We also drafted a future restoration area that should be considered longer term, if and when the native reefs and restoration areas have a healthy and reproductive population then we recommend deploying cultch on this site. This area is marked as "long-term" and encompasses 6.7 acres and joins the Woodman Point Native reef, Woodman Point current restoration site and Nannie Island restoration site (Figure 43).

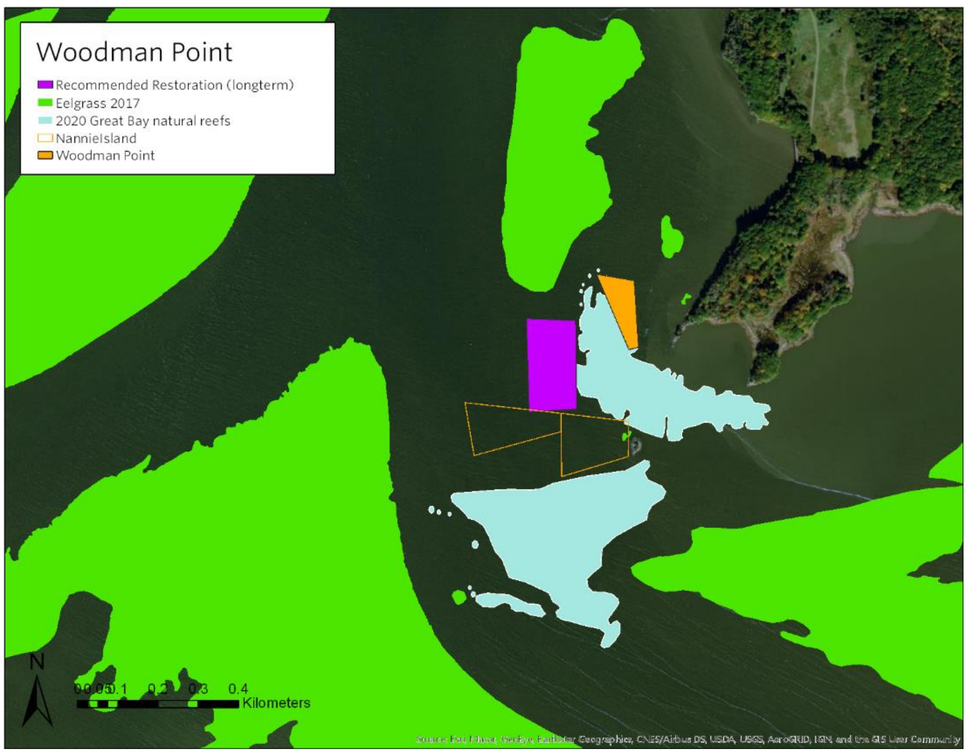


Figure 43. Proposed restoration site (purple) between the TNC Nannie Island restoration sites (outlined in orange), native oyster reef (blue), and Woodman Point restoration site (orange).

Table 9. Recommendations for future TNC oyster restoration work in the Great Bay Estuary.

Site	**Restoration Priority**	**Acreage**	**Methodology Recommendations**				**Note**
			Cultch	**Oyster**	**Eelgrass**	**Closure**	
Adams Point	Medium-low	**6.6** (2.6, 4*)	X	X		X	Monitor native reef, oyster deployment if closed
Footman Island	Low	**0**					Monitor for eelgrass recovery
Lamprey River	Low	**0**					Limited ability to work due to ACOE limits
Nannie Island	Medium to high	**17** (10, 7*)		X		X	Stock enhancement started in 2020
Oyster River	Medium	**2.5**	X		X		Pending dam removal
Piscataqua	Medium	**0** (8.5*)	X		x		Map current extent and condition of reef
Salmon Falls River	Low- no	**0**					Map current extent and condition of reef
Squamscott River	High	**9***	X				Monitor recruitment onto cultch site*
Woodman Point	Medium to High	**9.2** (2.5,6.7*		X		X	Monitor native reef, add adult oysters if closed, adaptative management for future area**
Total		**24.3** (52.8**)					

* Grizzle & Ward sites
** Long term site

Conclusion

In conclusion we are recommending deploying multiple restoration methods within **24-53** (includes new, existing and Grizzle& Ward, NRCS funded sites) acres across seven sites in the Great Bay Estuary. By utilizing multiple tactics, we aim to restore and build a network of reefs that are reproducing, filtering water and improving water quality and providing habitat for fish and invertebrates. We propose reef construction and placement of cultch on nearby reefs with high density of reproductive adults, to provide substrate and increase the probability of recruitment from native productive reefs. We suggest planting multiple year classes of oysters as stock enhancement on existing restoration sites adjacent to productive to provide a density of oysters to ensure reproductive success. We advocate for temporary closures at specific reefs to allow for populations to rebound to a more normal state. We support and endeavor to experiment and test coupled eelgrass and oyster restoration. We believe this multi-disciplinary and methodological approach will best advance the strategy of restoring oyster reefs and the ecosystems services they provide to the Great Bay Estuary System.

V. References

Atwood, R. L., & Grizzle, R. E. (2020). Eastern Oyster Recruitment Patterns on and Near Natural Reefs: Implications for the Design of Oyster Reef Restoration Projects. *Journal of Shellfish Research*, *39*(2), 283-289.

Baggett, L. P., Powers, S. P., Brumbaugh, R. D., Coen, L. D., DeAngelis, B. M., Greene, J. K.,& Bushek, D. (2015). Guidelines for evaluating performance of oyster habitat restoration. *Restoration Ecology*, *23*(6), 737-745.

Bilgili, A., Proehl, J. A., Lynch, D. R., Smith, K. W., & Swift, M. R. (2005). Estuary/ocean exchange and tidal mixing in a Gulf of Maine Estuary: A Lagrangian modeling study. *Estuarine, Coastal and Shelf Science*, *65*(4), 607-624.

Bricker, S. B., Grizzle, R. E., Trowbridge, P., Rose, J. M., Ferreira, J. G., Wellman, K., ... & Miller, R. L. (2020). Bioextractive Removal of Nitrogen by Oysters in Great Bay Piscataqua River Estuary, New Hampshire, USA. *Estuaries and Coasts*, *43*(1), 23-38.

Brumbaugh, R. D., & Coen, L. D. (2009). Contemporary approaches for small-scale oyster reef restoration to address substrate versus recruitment limitation: a review and comments relevant for the Olympia oyster, Ostrea lurida Carpenter 1864. *Journal of Shellfish Research*, *28*(1), 147-161.

Burdick, D. M., Moore, G. E., Mathieson, A. C., Payne, A., & Peter, C. (2019). Macroalgal Monitoring in the Great Bay Estuary: 2018 Annual Report.

Burdick, D. M., Edwardson, K. J., Gregory, T., Matso, K., Mattera, T., Paly, M., ... & Torio, D. D. (2020). A Case for Restoration and Recovery of Zostera marina L. in the Great Bay Estuary.

Caffrey, J.M., J.T. Hollibaugh, and B. Mortazavi. 2016. Living oysters and their shells as sites of nitrification and denitrification. *Marine Pollution Bulletin* 112: 86-90.

Carmichael, Ruth H., W. Walton, and H. Clark. 2012. Bivalve-enhanced nitrogen removal from coastal estuaries. *Canadian Journal of Fisheries and Aquatic Sciences* 69: 1131-1149.

Castagna, M., M.C. Gibbons, and K. Kurkowski. 1996. Culture: application. pp. 675-690 In: Kennedy, V.S., R.I.E. Newell, and A.F. Eble (eds.) The Eastern Oyster, Crassostrea virginica. Maryland Sea Grant, College Park, MD

Coen, L. D., Brumbaugh, R. D., Bushek, D., Grizzle, R., Luckenbach, M. W., Posey, M. H., ...Tolley, S. G. (2007). Ecosystem services related to oyster restoration. Marine Ecology Progress Series,341, 303–307. https://doi.org/10.3354/meps341303

Colden, A. M., Latour, R. J., & Lipcius, R. N. (2017). Reef height drives threshold dynamics of restored oyster reefs. *Marine Ecology Progress Series*, *582*, 1-13.

"Cross Grained & Wily Waters: A guide to the Piscataqua Martime Region, W. Jeffery Bolster, Editor 2002.

Eckert, R. L. (2016). Oyster (Crassostrea virginica) recruitment studies in the Great Bay Estuary, New Hampshire.

Grabowski, J. H., Hughes, A. R., Kimbro, D. L., & Dolan, M. A. (2005). How habitat setting influences restored oyster reef communities. *Ecology*, *86*(7), 1926-1935.

Grabowski, J. H., & Peterson, C. H. (2007). Restoring oyster reefs to recover ecosystem services. *Ecosystem engineers: plants to protists*, *4*, 281-298.

Grabowski, J. H., Brumbaugh, R. D., Conrad, R. F., Keeler, A. G., Opaluch, J. J., Peterson, C. H., ... & Smyth, A. R. (2012). Economic valuation of ecosystem services provided by oyster reefs. *Bioscience*, *62*(10), 900-909.

Grizzle, R.E., Brodeur, M. (2004) Oyster (Crassostrea virginica) reef mapping in the Great Bay Estuary, New Hampshire - 2003. (The New Hampshire Estuaries Project, Durham NH), p 19.

Grizzle, R.E., Ward, K. (2009) Video-Based Mapping of Oyster Bottom in the Upper Piscataqua River, Sturgeon Creek, and Spruce Creek. (University of New Hampshire, Durham NH), p 10.

Grizzle, R. E., & Ward, K. M. (2013). Oyster bed mapping in the Great Bay Estuary, 2012-2013.

Grizzle, R. E., & Ward, K. (2016). Assessment of recent eastern oyster (Crassostrea virginica) reef restoration projects in the Great Bay Estuary, New Hampshire: planning for the future.

Grizzle, R. E., & Ward, K. (2018).2017 Data Report. TNC UNH Oyster Restoration in Great Bay

Grizzle, R. E., & Ward, K. (2019).2018 Data Report. TNC UNH Oyster Restoration in Great Bay

Grizzle, R. E., & Ward, K. (2020a).2019 Data Report. TNC UNH Oyster Restoration in Great Bay

Grizzle, R. & K. Ward. (2020b). Assessing the success of NRCS-funded oyster reef restoration projects in New Hampshire from 2010-2018. Final Report. Submitted to: Natural Resources Conservation Service, Dover, NH

Grizzle, R. E., & Ward, K. (2020c). Mapping and Assessing Oyster reefs in the great bay Estuarine System. Final Report. Submitted to The Nature Conservancy

Group, B. 2019. The 2018 Oyster Conservationist Report. The Nature Conservancy.

Harding, J. M., & Mann, R. (1999). Fish species richness in relation to restored oyster reefs, Piankatank River, Virginia. *Bulletin of Marine Science*, *65*(1), 289.

Harper, T., Group, B., Laferriere, A.M. 2018. Recruitment dynamics TNC internal report

Heck Jr, K. L. (2019). Seagrass Ecosystems: A career-long quest to understand their inner workings. *Gulf and Caribbean Research*, *30*(1), ii-xv.

Higgins, C. B., Stephenson, K., & Brown, B. L. (2011). Nutrient bioassimilation capacity of aquacultured oysters: quantification of an ecosystem service. *Journal of environmental quality*, *40*(1), 271-277.

Laferriere, A.M & Group, B. 2020 Stock Enhancement field notes. TNC internal report

Latimer J.S. and S.A. Rego. 2010. Empirical Relationship Between Eelgrass Extent and Predicted Watershed-derived Nitrogen Loading for Shallow New England Estuaries. *Estuarine, Coastal and Shelf Science* 90: 231-240

Lenihan, H. S., Grabowski, J. H., & Thayer, G. W. (1998). Recruitment to and utilization of oyster reef habitat by commercially and recreationally valuable crabs and fishes: an experiment with economic analysis (No. 1-97). Final Report.

Lippmann, T.C. 2019. Bathymetric surveys in support of oyster reef restoration. Final Report submitted to The Nature Conservancy.

Lipcius, R. N., Burke, R. P., McCulloch, D. N., Schreiber, S. J., Schulte, D. M., Seitz, R. D., & Shen, J. (2015). Overcoming restoration paradigms: value of the historical record and metapopulation dynamics in native oyster restoration. *Frontiers in Marine Science*, *2*, 65.

Matso, K., Mattera, T., Short, F., Burdick, D., Martin, L., Sarrette, N., ... & Gregory, T. (2020). SeagrassNet Monitoring in the Great Bay Estuary, NH/ME Field Season 2019.

Moeser, A. 2018. The 2017 Oyster Conservationist Report. The Nature Conservancy.

New Hampshire Fish and Game (NHF&G). 2019. Oyster Review Data memo. Interdepartmental Communication

Newell, R. I. (2004). Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve molluscs: a review. *Journal of Shellfish research*, *23*(1), 51-62.

Newell, R. I., Fisher, T. R., Holyoke, R. R., & Cornwell, J. C. (2005). Influence of eastern oysters on nitrogen and phosphorus regeneration in Chesapeake Bay, USA. In *The comparative roles of suspension-feeders in ecosystems* (pp. 93-120). Springer, Dordrecht.

Odell, Jay; Eberhardt, Alyson.; Burdick, David M.; and Ingraham, Pete, "Great Bay Estuary Restoration Compendium" (2006). *PREP Reports & Publications.* 150. https://scholars.unh.edu/prep/150

Piehler, M. F., & Smyth, A. R. (2011). Habitat-specific distinctions in estuarine denitrification affect both ecosystem function and services. *Ecosphere*, *2*(1), 1-17.

PREP. 2018. State of Our Estuaries 2018. *PREP Publications.*

Reichert-Nguyen, J. (2018). Oyster BMP expert panel update to the Chesapeake Bay program water quality goal implementation team, Annapolis MD. *Chesapeake Bay Panel Oyster BMP Expert Panel available online at https://oysterrecovery. org/wp-content/uploads/2015/10/Update-on-Oyster-BMP-Expert-Panel-2nd-Report_2-1-18_Final. pdf*.

Rose, J. M., Bricker, S. B., Tedesco, M. A., & Wikfors, G. H. (2014). A role for shellfish aquaculture in coastal nitrogen management .

Sandoval-Gil, J., Alexandre, A., Santos, R., & Camacho-Ibar, V. F. (2016). Nitrogen uptake and internal recycling in Zostera marina exposed to oyster farming: eelgrass potential as a natural biofilter. *Estuaries and Coasts*, *39*(6), 1694-1708.

Schulte, D. M., Burke, R. P., & Lipcius, R. N. (2009). Unprecedented restoration of a native oyster metapopulation. *Science*, *325*(5944), 1124-1128.

Short, F.T. 1992 (ed.) The Ecology of the Great Bay Estuary, New Hampshire and Maine: An Estuarine Profile and Bibliography. NOAA – Coastal Ocean Program Publ. 222 pp.

Short, F. T. (2016). Eelgrass Distribution and Biomass in the Great Bay Estuary for 2015.

Supan, J.E., C.A. Wilson and K.J. Roberts. 1999. Economics of augmentation of natural production using remote setting techniques. pp. 359-366 In: Luckenbach, M.W., R.

Mann, and J. Wesson (eds.) Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. Virginia Institute of Marine Science, Gloucester Point, VA.

Thayer, G. W., Kenworthy, W. J., & Fonseca, M. S. (1984). *The ecology of eelgrass meadows of the Atlantic coast: a community profile*. Fish and Wildlife Service, US Department of the Interior.

Zu Ermgassen, P. S., Spalding, M. D., Grizzle, R. E., & Brumbaugh, R. D. (2013). Quantifying the loss of a marine ecosystem service: filtration by the eastern oyster in US estuaries. *Estuaries and coasts*, *36*(1), 36-43.

Zu Ermgassen, P. M., Hancock, B., DeAngelis, B., Greene, J., Schuster, E., Spalding, M., & Brumbaugh, R. (2016). Setting objectives for oyster habitat restoration using ecosystem services: a manager's guide. *The Nature Conservancy: Arlington, VA, USA*.

VII. Appendices

Appendix 1: Oyster Restoration by Design Public Participation Plan

Oyster Restoration by Design

Public Participation Plan

November 30th, 2018

Note: This plan was created in the Spring of 2018 to guide activities to take place in late Spring through November 2018. In November 2018, modifications were made to accurately capture the activities that took place during its implementation.

Purpose of this Document

The purpose of this Participation Plan, designed by the Piscataqua Region Estuaries Partnership (PREP) in collaboration with The Nature Conservancy (TNC), is to clearly outline the context and goals of the stakeholder engagement process of the "Oyster Restoration by Design" project.

Background

Oysters play a critical role in maintaining the health and resilience of the Great Bay Estuary. Each bivalve can filter up to 30 gallons of water per day, removing suspended particles and clearing the surrounding waters. Additionally, their reefs provide important habitat for native fish and invertebrates and can help alleviate erosion and buffer shorelines. As part of the Great Bay 2020 initiative, TNC has identified oyster reef restoration as an essential strategy for improving the conditions in Great Bay and currently has restored 24.7-acre footprint in the bay.

TNC is developing a spatially explicit, oyster restoration plan to guide near-term oyster restoration opportunities in the Great Bay Estuary. The plan will include a review of past restoration efforts and identification of new sites. Additionally, the plan aims to integrate and balance site suitability for oyster restoration with additional interests, such as recreational harvest areas, oyster aquaculture opportunities, and eelgrass regeneration areas. To this end, TNC has worked with key stakeholders and held meetings to solicit comments on the restoration plan, and adjusted the plan as needed to accommodate various concerns or conflicts.

Steering Committee

In January 2017, a steering committee was established that consisted of multiple stakeholders from organizations including TNC, PREP, NH Department of Environmental Services, NH Coastal Program, NH Fish & Game, Great Bay National Estuary Research Reserve, NH Sea Grant, and Natural Resources Conservation Service. The primary role of the Steering Committee was to oversee and guide the public involvement process, with an emphasis on who to involve, how to involve them, and how to clarify the decision-making process. From the beginning, the Steering Committee made it clear that the primary decision-maker was TNC, and the purpose of the public involvement was to inform TNC's decision.

Major Issues

The following issues were identified during the preliminary planning and Steering Committee meetings:

- ***Spatial conflict of oyster & eelgrass restoration:*** In addition to oysters, eelgrass is viewed by many stakeholders as a highly valuable habitat in Great Bay. Areas suitable for oyster restoration may also be suitable for eelgrass restoration or be located in areas of historic eelgrass beds. Therefore, certain agencies and scientists may oppose oyster restoration in areas they view as better suited for eelgrass.
- ***Habitat conversion:*** While oyster reefs are viewed by many as a valuable habitat, the creation of a reef converts the habitat that currently exists at the restoration site, such as mudflat. Some permitting agencies and scientists may be concerned with this conversion.
- ***Balancing restoration & future shellfish aquaculture areas:*** There are limited areas in Great Bay where oyster growers may lease space to raise oysters for harvest. Growers may, therefore, oppose the creation of an oyster restoration site, which is closed to harvesting, established in an available lease area.
- ***Landowners not wanting visual signs of restoration work:*** Restoration efforts require the use of barges and machinery that may not be visually appealing to those abutters of such projects. Therefore, landowners may have concerns or objections to such work near their property along the water.
- ***Restoration interfering with recreational use:*** Recreationalists such as boaters, kayakers, recreational harvesters, and anglers may be concerned that restoration activities block or hinder their access to the water resource they use for recreation.
- ***Project permitting:*** Projects within NH wetlands are significantly regulated. State and federal permitters, as well as local planning boards and conservation commissions, will need to be aware of and authorize any restoration project that is to take place in Great Bay.
- ***Improving Great Bay water quality:*** There are many individuals and organizations actively working with the interest of improving the water quality in Great Bay. Although

oysters play a role in this effort, it often means striking the right balance for different habitats. Therefore, those stakeholders would likely want to have a voice in this process.

- ***Opportunities to be involved in restoration:*** Not all issues are negative, and stakeholders, such as growers, landowners, municipalities, etc., may want to be involved in the restoration planning, influencing the decision and encouraging restoration effort.

Issues Management Program

The following issues management activities took place to address the major issues identified:

- ***Spatial conflict of oyster & eelgrass restoration:*** During Stage 3 Phase 1 (described below), technical reviewers specializing in oysters, eelgrass, and related ecosystems in Great Bay were interviewed individually in order to better understand potential conflicts. Technical reviewers external to those located in NH were also contacted to provide additional perspectives on this issue as well.
- ***Habitat conversion:*** During Stage 3 Phase 2, representatives from regulatory agencies that would be involved in the review and permitting of an oyster restoration project were consulted in a group meeting to confirm the areas and types of restoration that would be permittable. At this phase, regulatory actors concerned with habitat conversion were able to review potential sites and restoration activities and voice their concerns.
- ***Balancing restoration & future shellfish aquaculture areas:*** When possible, active and available areas of oyster aquaculture were avoided in siting potential restoration sites Additionally, NH Fish & Game was consulted to review proposed areas of restoration during Stage 3 Phase 2, and several growers were individually interviewed during Stage 3 Phase 3 to determine if there would be conflict with ideal sites of restoration. These parties were also invited to contribute during the stakeholder workshop.
- ***Landowners not wanting visual signs of restoration work:*** After potential sites are narrowed down through technical and regulatory discussions in Stages 1 & 2 and evaluated in Stage 4, abutters can be identified and individually engaged to hear the proposed plans and provide their input.
- ***Restoration interfering with recreational use:*** Establishments of social and recreational interests were identified and invited to participate at the stakeholder workshop, while being encouraged to pass on the invitation to those they think would also be interested.
- ***Project permitting:*** As described above, representatives from regulatory agencies were involved in a group meeting during Stage 3 Phase 2 to review proposed sites and methods for restoration in order to confirm what may be permittable and what may not be.
- ***Improving Great Bay water quality:*** Some stakeholders from organizations whose goals include improving the water quality in the Great Bay Estuary were interviewed during Stage 3 Phase 3 in order to capture their perspective, while all identified organizations were invited to participate in the stakeholder workshop.
- ***Opportunities to be involved in restoration:*** Communication of this project was made public through means of direct communications and emails, an informational handout,

and newsletter articles. These communications had contact information for those that wanted to become involved, and any individuals that would support this effort were encouraged to participate at the workshop as well.

Level of Interest

With the high density of local organizations and individuals working on water quality and related issues in the Great Bay Estuary and the number of activities, values, and resources that could be affected by restoration efforts, the level of stakeholder interest was expected to be very high, justifying an extensive public participation process.

Interested Groups

A number of local scientists and experts specializing in wetlands, restoration, ecosystems, oysters, eelgrass, and the Great Bay Estuary are interested in this project and want to contribute their input and perspectives. Local environmental organizations & NGOs focused on the same topics are also interested.

Regulators & permitters will need to be kept aware of this project due to the significance and complexity of the regulatory process of wetland projects. Likewise, the municipal planning boards and conservation commissions of the communities in which the preferred sites are located will be interested and may need to authorize proposed work.

As this work could potentially be located in areas available to oyster growers and harvesters, they are interested and may provide input for the decision-making process. Additionally, there may be interest from them to become involved in the future oyster restoration efforts.

Landowners and abutters of the restoration site(s) on the Great Bay Estuary may be interested in this process, whether due to concern of the aesthetics and disturbance of restoration activities or to a desire to learn about and become involved with active oyster restoration efforts in the Bay.

Local recreationalists may be interested in this project if there is the potential to disrupt or impede recreational activities in the areas they frequent. However, similar to previously mentioned stakeholder groups, there also may be interest in learning about and becoming involved with oyster restoration efforts.

Decision-Making Process

The basic stages in the design of the restoration plan and timeline were as follows:

Stage	*Timeframe*
Stage 1: Develop a problem statement and plan goals	Jan-Apr 2018
Stage 2: Establish evaluation criteria for the restoration work	Mar-Apr 2018

Stage 3: Develop options	May-Aug 2018
Stage 4: Evaluate options	Aug-Sept 2018
Stage 5: Select preferred suite of options	Sept-Oct 2018
Stage 6: Document process and resulting plan in final report	Nov-Dec 2018

<u>Public Participation Activities</u>

Below are the specific public participation activities that were conducted at each stage in the decision-making process:

Stage 1: Develop a problem statement and plan goals

During this stage, the key stakeholders that made up the project's Steering Committee were introduced to the project, project scope, and proposed process. They were given the opportunity to raise concerns of issues they observed and make suggestions to help refine the scope of the project and accompanying process. The objective of this first stage was to ensure that the key stakeholders on the Steering Committee understood and were satisfied with the context, stages, and goals of the project. The public participation activities during this stage included:

1. Conducting two facilitated Steering Committee meetings to discuss 1) project and scope, 2) aspects of Decision Analysis, 3) lists of stakeholders, issues, and levels of involvement, 4) and the public participation plan. These meetings were held on January 22nd and April 25th, 2018.
2. Holding follow-up conversations with Steering Committee members via email throughout this time period.

Stage 2: Establish evaluation criteria for the restoration work

This stage set the criteria that will be used by TNC to make decisions. (Rather than one overall decision, this project encompasses multiple decisions that will need to be made for a set number of distinct areas in the Great Bay Estuary where oyster restoration can even be considered. For each area, decisions need to be made related to types of restoration activities.) Potential criteria include: likelihood of oyster restoration success; level of conflicts with other uses; ease of permitting, etc.

Technical stakeholders that are external to the NH process were consulted to provide feedback into initial criteria, which were then presented to the Steering Committee for further review and recommendations. The public participation objective of this stage was to get agreement from key stakeholders on the criteria to be used to evaluate sites. The public participation activities during this stage included:

1. Holding conversations with external technical reviewers, including restoration specialists from TNC, through emails and individual interviews to discuss initial evaluation criteria.

2. Conducting a facilitated Steering Committee meeting on August 2nd, 2018 with the Steering Committee to review developed criteria.

Stage 3: Develop options

During this stage, a range of key stakeholders were engaged individually or in small groups to help discuss and identify potential restoration sites that were displayed on iterative maps used for further stakeholder meetings. This stage was broken into three phases (Fig.1 below) that focused on input from different classifications of stakeholders: 1) technical reviewers, 2) regulatory stakeholders, and 3) stakeholders of aquacultural & social interests. Maps were revised throughout each phase. The primary public participation objective of this stage was to understand both technical and non-technical concerns of stakeholders. An additional objective was to make stakeholders aware of an upcoming workshop to discuss and evaluate options. The public participation activities during this stage included:

1. Conducting a series of individual meetings and interviews from May through July with technical reviewers to determine where in the Great Bay Estuary is physically and environmentally appropriate for oyster restoration.
2. Conducting a focus group on July 23rd and individual meetings afterwards with regulators and permitters to determine where in the Great Bay Estuary is available or problematic for restoration due to current and/or future rules and regulations.
3. Conducting a series of meetings with a sub-sample of growers and NGO representatives to discuss initial developed options and gather feedback based on their concerns and perspectives.

Stage 4: Evaluate options

During this stage, the options developed for potential restoration sites were discussed among stakeholders to identify preferred options. The primary public participation objective was to develop as high a level of consensus as possible on the preferred options. The public participation activities included:

1. Conducting a facilitated Steering Committee meeting on August 2nd, 2018 to review stakeholder involvement activities throughout the summer and to discuss the following stakeholder workshop.
2. Hosting a facilitated evaluation workshop on August 24th, open to all interested stakeholders, which was comprised of both large group and small group discussions among participants to collect feedback.
3. Further public engagement through electronic communications, one-on-one conversations, and small group meetings to address additional questions and concerns.

Stage 5: Select preferred suite of options

After TNC selects preferred options based on the evaluation criteria developed, the Steering Committee will review that final suite of options. The primary public participation objectives were to ensure that the stakeholders of the Steering Committee understood and were allowed to provide feedback on summarized findings and preferred options from the workshop. The public participation activity included:

1. Conducting a facilitated Steering Committee meeting on October 23rd to review and discuss the stakeholder feedback and the preferred suite of options that came out of the stakeholder workshop.

Stage 6: Document process and resulting plan in final report

A report of the project will be developed by TNC that includes this public participation process, the resulting plan, and a summary of alternative viewpoints. The objectives are to capture and report to interested parties an accurate description of the public participation process that was designed and used throughout this project. The public participation activities will be:

1. Circulate a draft report with Steering Committee members for review.
2. Share the final report with all stakeholders involved in the process.
3. Utilize existing communication channels to share the final report to interested parties beyond those that were directly involved in the project and process.

Review Points

Aspects of the public participation plan (while under development) were reviewed by Steering Committee members during Stage 1 (March-April 2018), and the final participation plan was circulated and reviewed by the Steering Committee at the August 2nd meeting.

Fourteen formal meetings were held between PREP and TNC during the period between January and November 2018 in order to discuss and prepare all aspects of this process, including identification of stakeholders and issues, meetings and meeting materials, focus groups and workshops, and data collection and analysis.

Appendix 2: Bathymetric Surveys in Support of Oyster Reef Restoration

Final Report
(To Dr. Alix Laferriere, TNC, 09 December 2019)
Bathymetric surveys in support of oyster reef restoration

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This is the final report for the contract entitled "Bathymetric surveys in support of oyster reef restoration" under Subaward TNC-NH/NRCS/UNHMapping/05222017. The overall aim of the project was to conduct multiple multi-beam bathymetric surveys over oyster reef restoration sites (Figures 1 and 2) in the Great Bay Estuary, and determine depth changes over a 2.5 year period from June 2017 through November 2019 that includes deployment of artificial reef shell mounds. Surveys were conducted before and after shell deployments over a 5-acre site near Nannie Island, 2.5 acre site near Woodman Pt., and 1 acre and 2 acre sites near the Lamprey River. A bottom-mounted, upward-looking acoustic Doppler current profiler (ADCP) was deployed in the center of the Nannie Island restoration site for 40 days in the summer of 2018 to assess the current strength over a typical spring-neap tidal cycle. Additional surveys were conducted in August 2018 over existing natural oyster reef sites in the Oyster River, near the Lamprey River, and near Nannie Island in support of vibra-coring by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Services (NRCS), and also in July 2019 at the Adam's Pt. natural reef site in support of ongoing collaborative work between UNH and TNC. The surveys over the natural reefs can serve as a baseline for future studies and guide monitoring or restoration efforts in those areas. The work was amended in 2018 to include an analysis of acoustic backscatter waveform data obtained in 2015/2016 over the entire Great Bay Estuary, in an effort to characterize the seabed in terms of existing oyster reef habitat for future restoration site selection.

A total of 23 multi-beam bathymetric surveys were conducted over the project period (Table 1). Pre-surveys were conducted at each restoration site (12 June 2017 at Nannie Island, and on 09 May 2018 at Woodman Pt. and the 2 Lamprey River sites) prior to artificial shell deployments (July 2017 at Nannie Island and August 2018 at the other sites). Six post-deployment surveys were then conducted at the Nannie Island site over the following 2.5 years and used to observe changes to the bathymetry and artificial reef mounds. Three post-deployment surveys were conducted at the Woodman Pt. and Lamprey River sites over the following 1 year period and used to assess the bathymetric evolution there. A total of 22, 14, and 10 mounds were identified and monitored at the Nannie Island, Woodman Pt., and south Lamprey River sites, respectively. No mounds were discernible in the survey at the north Lamprey River site (either due to low elevation reef mounds or bathymetric changes that masked the locations of deployed shell). Observed mound elevations at the Nannie Island site ranged 0.30 – 0.75 *m* and had spatial diameters at the base of 5 – 10 *m*. Elevation profiles across the approximate center of each mound were extracted from each survey and compared. In all cases, over the 2.5 years following shell deployment the mounds showed very little variation, generally within the resolution of the bathymetric surveys (about 0.10 *m*). Observed mounds at both the Woodman Pt. and south Lamprey sites had similar elevations and spatial extent, and also showed very little change over the 1 year period following shell deployment. Hourly and depth-averaged currents at the Nannie Island site were strongly controlled by the tides, and reached magnitudes of 0.5 *m/s* during spring tidal cycles. The observed currents are typical of the site, and are similar to observations obtained at the same site during August – October 2015. Currents at the Woodman Pt. and Lamprey sites were not measured, but are known to be weaker than at the Nannie Island location (based on numerical modeling of currents in the Great Bay; Cook, *et al*., 2019). Icing conditions in the Great Bay were present in both the winter of 2017-18 and 2018-19, but were not quantified. In general, all mounds at all sites showed little change during the study period indicating that the artificial reefs were not strongly affected by the ambient currents or any icing conditions during winter months.

Acoustic backscatter waveform data obtained in 2015-16 with a 24 *kHz* single-beam sonar along transects spaced 25 *m* and spanning the Great Bay Estuary were examined in two ways. In the first, waveforms were decomposed into principal components using standard EOF (empirical orthogonal function) decomposition. Each EOF represents a percentage of the variance of the data, and has spatial weighting that shows how each EOF varies across the Estuary. The first 2 factors represent 46.8% and 20.3% of the variance, respectively, and show coherent spatial patterns that reflect the character of the Great Bay, including the location of tidal channels, mud flats, and eelgrass meadows. However, the relationship between spatial EOF weighting and know oyster reef locations was not strongly reflected in the data, and could not be used to identify other similar locations across the Bay.

In the second method, maximum and mean backscatter intensity maps at 0.25 *m* increments from the seafloor to 5 *m* below the sea bed were produced for the same 24 *kHz* waveform data. These data show the spatial variation of stronger reflections at given depths and reveal similar characterization of the estuary as the EOF decomposition. In particular, the backscatter from the top 0.25 *m* and from 1.00-1.25 *m* below the seabed compare well with the first and second EOF's, respectively, indicating that these reflectors contain the bulk (77.1%) of the variability in the Great Bay. In the main tidal channel, high backscatter occurs owing to the coarser bed material (as finer sediments are winnowed away by the strong currents). Over the mud flats, the sonar penetrates to the deeper layers and reveals subsurface variation that qualitatively appear to be paleo channels cutting across the mudflats and eelgrass meadows. The nature of the backscatter at depths of 1 *m* or more could be regions with oyster shell, but would require deep (> 2 *m*) cores in strategic locations to reveal the nature of the substrate. In general, the spatial variability of the backscatter across the estuary did not reveal strong coherence with known oyster reefs, but qualitatively revealed coherent spatial patterns within the seafloor sediments that might reflect past tidal channels, sedimentation patterns, or old reefs.

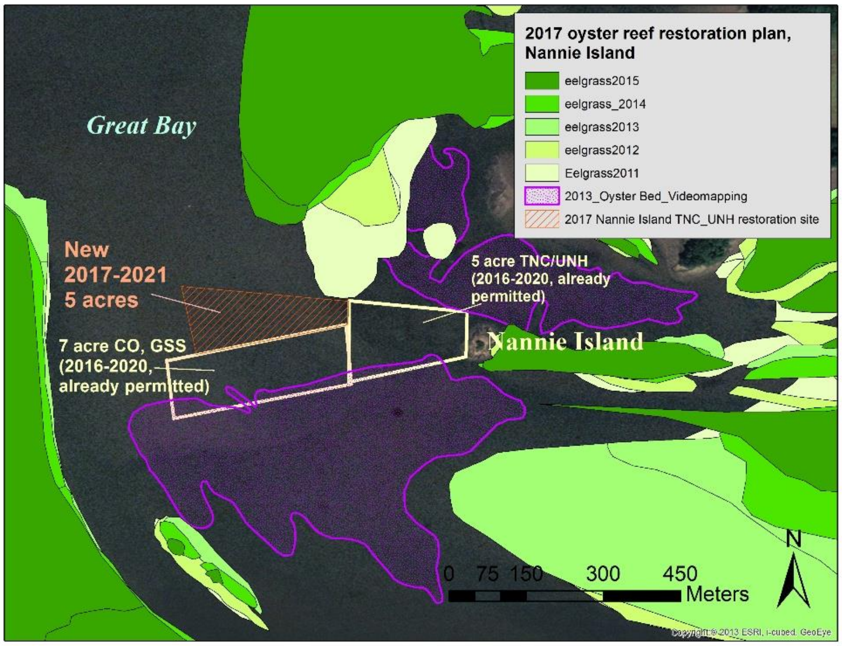


Figure 1. Map of the target 5 acre region (red hatched region denoted "New 2017-2021") where bathymetric surveys were conducted in the summer of 2017. Also shown are other permitted areas, Nannie Island, eelgrass extent for years 2011-2015, and video mapping done in 2013. Scale is shown in the lower right hand corner. Figure courtesy of Ray Grizzle and Krystin Ward, UNH.

Figure 2. Maps of the 2018 restoration regions. Left panel shows the Woodman Pt. 2.5 acre region outlined in red. Right panel shows the north (1 acre) and south (2 acre) restoration regions (in red) near the mouth of the Lamprey River. Also shown on the right is the outline of the 1 acre Lamprey River natural reef (in between the red restoration areas) that was surveyed on 03 August 2018 as part of the NCRS drilling activities. Figures courtesy of Ray Grizzle and Krystin Ward, UNH.

Table 1. Timeline of Bathymetric Surveys Conducted.

Region	Date	Activity
Nannie Island Restoration	12 Jun 2017	CBASS survey
	12 Jul 2017	Shell Deployment
	31 Jul 2017	CBASS survey

	15 Nov 2017	CBASS survey
	10 Apr 2018	CBASS survey
	11 Jul – 20 Aug 2018	ADCP deployment
	27 Jul 2018	Zego survey
	30 Apr 2019	Zego survey
	30 Oct 2019	Zego survey
Woodman Pt. Restoration	09 May 2018	CBASS survey
	Aug 2018	Shell Deployment
	16 Sep 2018	Zego survey
	13 Apr 2019	Zego survey
	30 Oct 2019	Zego survey
Lamprey North Restoration	09 May 2019	CBASS survey
	Aug 2018	Shell Deployment
	16 Sep 2018	Zego survey
	02 Apr 2019	Zego survey
	09 Oct 2019	Zego survey
Lamprey South Restoration	09 May 2019	CBASS survey
	Aug 2018	Shell Deployment
	16 Sep 2018	Zego survey
	13 Apr 2019	Zego survey
	09 Oct 2019	Zego survey
Oyster River Natural Reef	02 Aug 2018	Zego survey
Lamprey River Natural Reef	03 Aug 2018	Zego survey
Nannie Island Natural Reef	03 Aug 2018	Zego survey
Adam's Pt. Natural Reef	03 July 2019	Zego survey

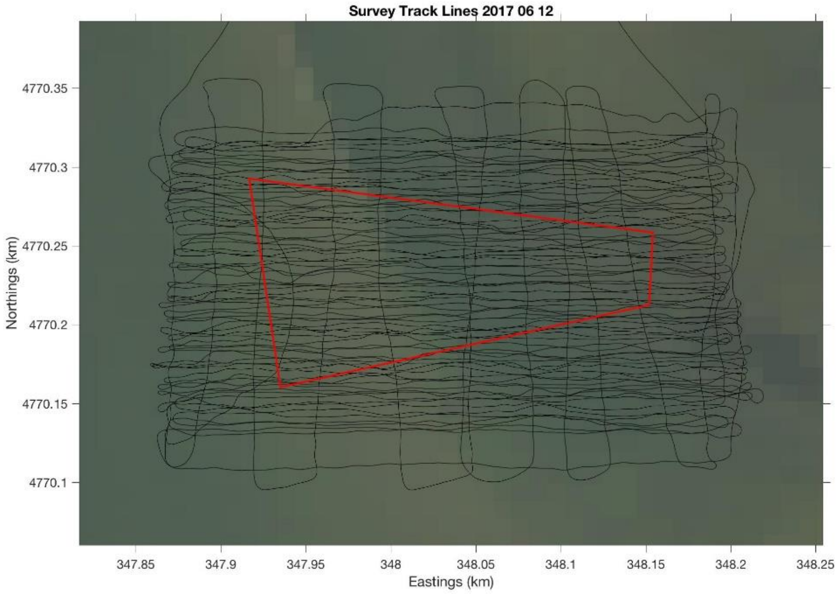
General Approach for Mapping Restoration Sites

The general work plan was to conduct detailed bathymetric mapping (with multi-beam sonar) prior to reef deployment, again soon after deployment of shell, and then several times over the next 1-2 years.

Detailed bathymetric surveys were conducted with both the Coastal Bathymetry Survey System (CBASS) and the Zego Boat Survey System. The CBASS (Figure 3) is a Yamaha GP1200 waverunner equipped with 240 *kHz* multi-beam echosounder (Imagenex Delta-T), 192 *kHz* single-beam echosounder, Applanix POS-MV 320 inertial measurement unit, and custom navigation with display. The CBASS is capable of observing seabed water depths with vertical resolution of about 5-10 *cm*, and horizontal resolution of 10-25 *cm* in water depths ranging 1-20 *m*. The Zego boat (Figure 3) is a 14 *ft* catamaran powered with an outboard motor, and equipped with the same instrumentation as the CBASS, and has resolution similar to the CBASS.

Figure 3. Picture of the CBASS (top) during survey on 12 June 2017, and Zego Boat (bottom) during survey conducted on 03 August 2018.

Surveys were conducted typically over a 4 *hr* period bracketing high tide. Typical survey tracks for the Nannie Island Restoration site are shown in Figure 4, with the 5-acre restoration site outlined by red lines. Survey lines were spaced approximately 2.5 – 3.5 *m*, depending on conditions keeping the vessel on track, and cross-lines were done for each survey. Survey track lines for the other sites were based on the same spacing as for Nannie Island (and not shown for brevity). Ping rates for the sonar ranged 3.75 *hz* to 10 *hz*, depending on multibeam range that depended on water depth. The multi-beam data obtained from each survey was processed, filtered, and then gridded to 0.25 *m*, 1.00 *m*, and 2.50 *m* resolution. Raw elevations are relative to the WGS84 ellipsoid, and are then transformed to orthometric heights (relative to the NAVD88 datum) using software provided by the National Geodetic Survey (programs *intg.f* and *htdp.f* converted to MATLAB scripts). Note that mean sea level is within a few *cm* of NAVD88.



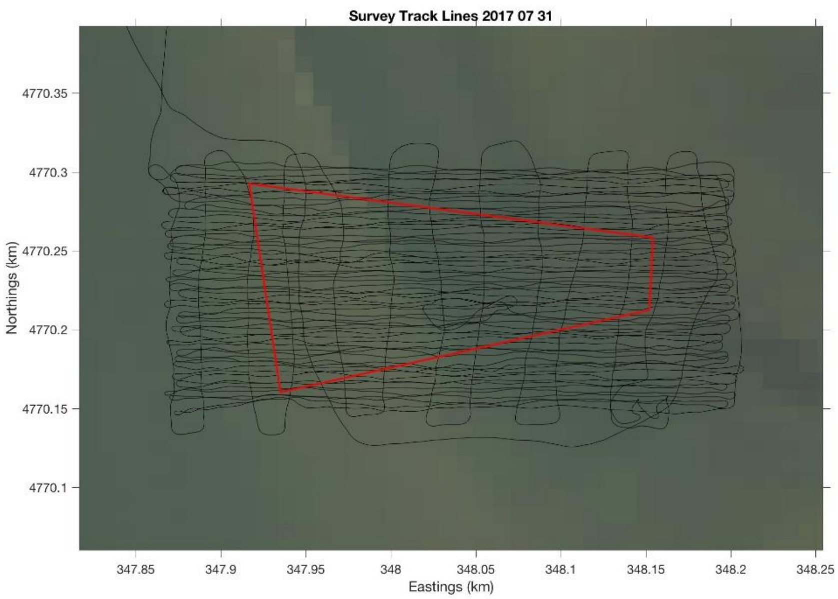


Figure 4. Map of the survey track lines for surveys on 12 June 2017 (top) and on 31 July 2017 (bottom). Horizontal x and y coordinates are *km* in eastings and northings. The solid red line outlines the region encompassing the 5-acre artificial oyster reef region. The surveys were conducted about high tide with the CBASS and took approximately 4 hours each day.

<u>Nannie Island Restoration Site</u>

The initial bathymetric map with 25 *cm* horizontal resolution obtained from a survey conducted on 12 June 2017 at the Nannie Island site prior to shell deployment is shown in Figure 5 with elevations relative to NAVD88. These data were used to guide the deployment of shell mounds by collaborators (Dr.'s Grizzle and Laferriere) on 27 June 2017. Also shown in Figure 5 is the location of the Nortek AWAC acoustic Doppler current profiler (ADCP) deployed for 40 days between 11 July 2018 and 20 August 2018 (discussed later). This is the same location sampled earlier by a similar ADCP in 2015.

A second survey was conducted on 31 July 2017, about 34 days after shell deployment. The vessel tracks for this survey are shown in Figure 4. The multi-beam data were processed in a similar manner as for the first survey, and were gridded to 25 *cm* resolution with grid cells that correspond to the first survey. The bathymetric map at 25 *cm* resolution is shown in Figure 6, with the elevations relative to NAVD88 indicated by the colorbar on the right-hand-side of the figure. The outline of the 5-acre restoration region is shown in the figure. The presence of the artificial oyster mounds is evident in the bathymetric map.

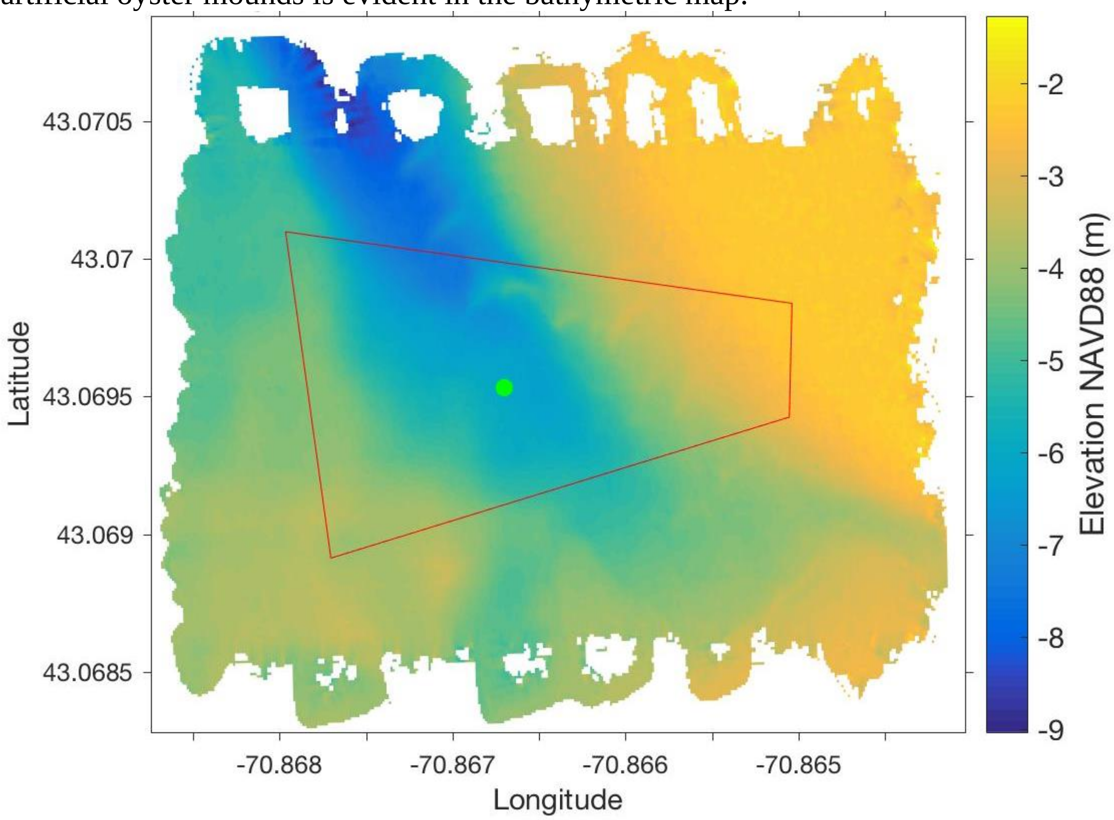


Figure 5. Bathymetric map of the survey region conducted on 12 June 2017. Horizontal resolution is 25 *cm*. Elevations are in *m* relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-hand-side. Horizontal coordinates are east longitude (*deg*) and north latitude (*deg*). The solid red line outlines the region encompassing the 5-acre artificial oyster reef region. Green dot indicates location of the ADCP deployed from 11 Jul–20 Aug 2018.

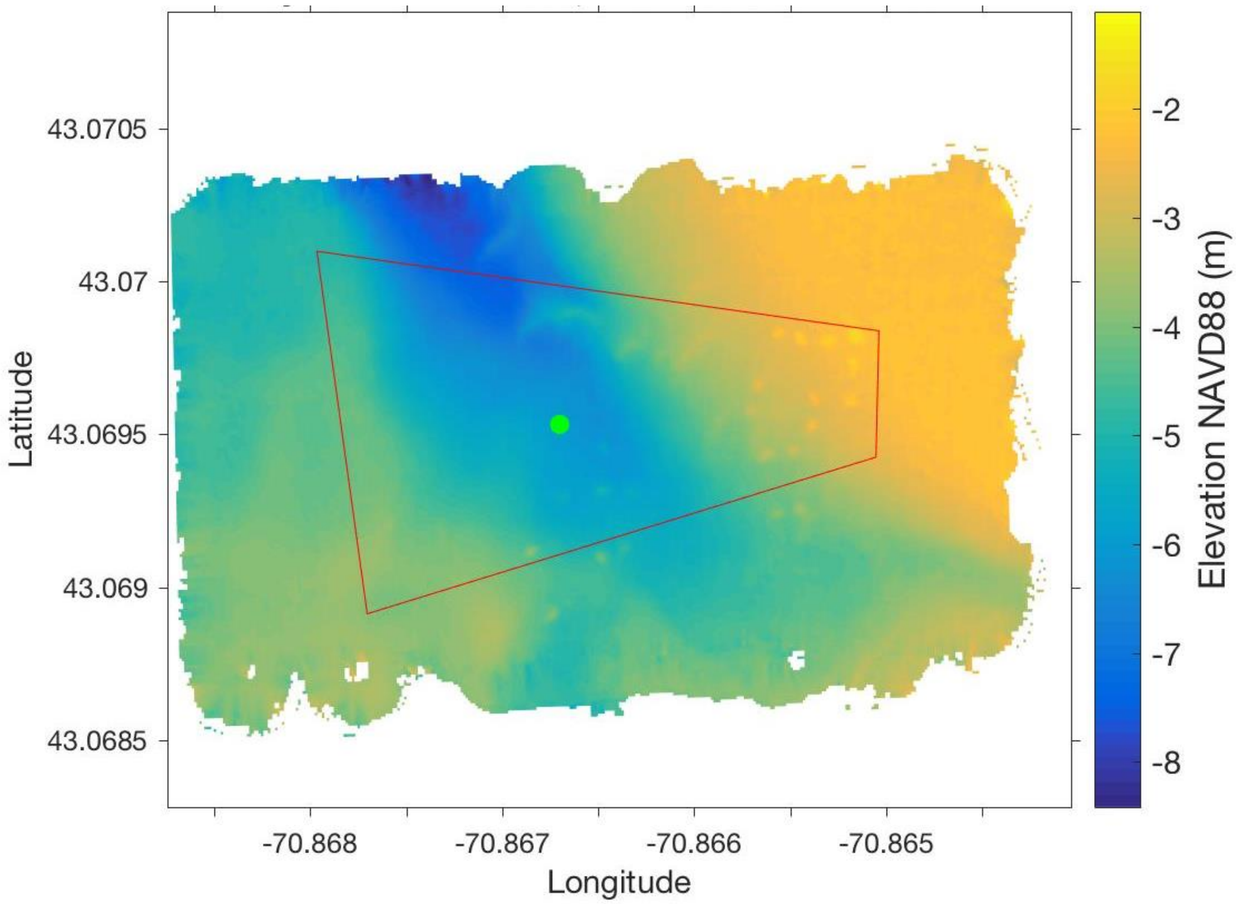


Figure 6. Same ad Figure 5 but for the survey conducted on 31 July 2017.

To better identify the locations and sizes of the deployed oyster shell, a difference map was produced by subtracting the bathymetry collected on 12 June 2017 from the bathymetry obtained on 31 July 2017. The difference map is shown in Figure 7 with the colorbar indicating the change in elevation with red colors indicating accretion (or gain of material) and blue colors indicated erosion (or loss of material). The resolution of the multi-beam system on the CBASS is about 5-10 *cm*, so that changes in depths with +/- 10 *cm* are resolvable with the surveys. The oyster mounds are clearly evident with the 20 – 50+ *cm* increases in elevation during the second survey (the reddish blotches in the figure).

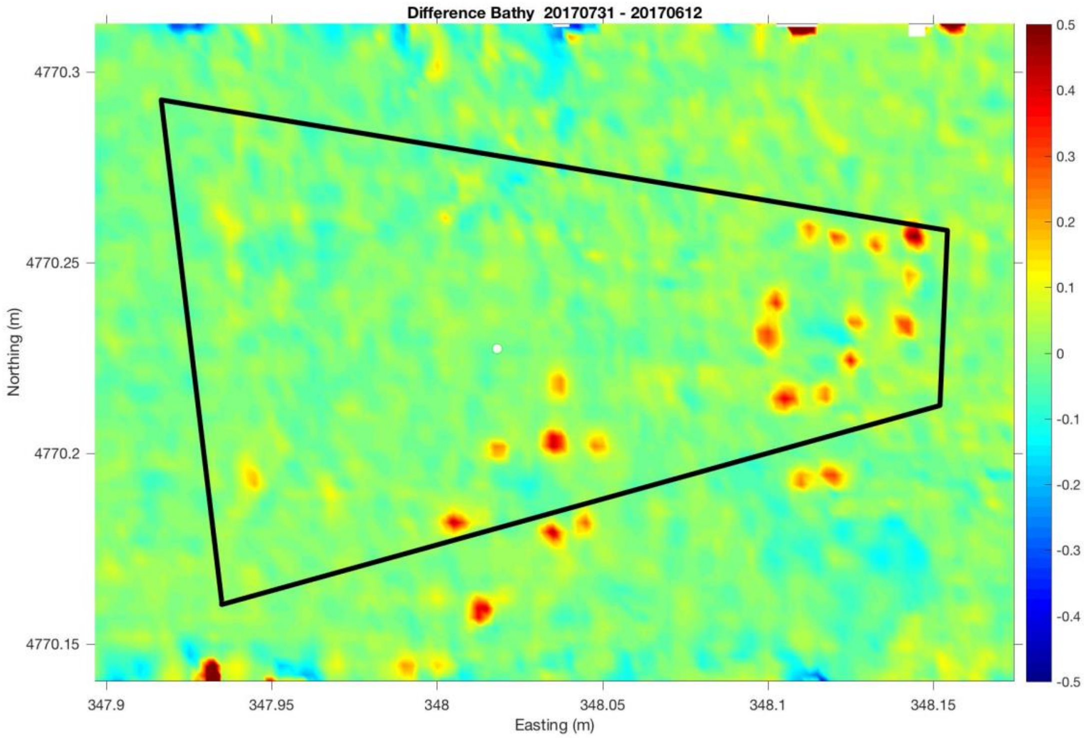


Figure 7. Difference elevation map between surveys obtained at Nannie Island on 12 June and 31 July 2017. Locations of deployed oyster shells are easily identified by elevated mounds (reddish colors). Horizontal resolution is 25 *cm*. Elevation differences are in *m* and given by the colorbar on the right-hand-side. Horizontal coordinates are *km* in eastings and northings. The solid black line outlines the region encompassing the 5-acre artificial oyster reef region. White dot indicates the location of an ADCP deployed from 11 July – 20 August 2018.

The locations of the mounds are identified using a threshold of +15 *cm* in the difference map. The locations identified with this threshold are shown in Figure 8 overlain on a map of the bathymetry (with 1.0 *m* resolution) observed on 31 July 2017. This map shows where the oyster mounds were deployed within the restoration region, in what water depths, and their position relative to the deep channel that cuts through the area. These maps can also guide physical inspection of the deployed oyster mounds. The location of twenty-two artificial reef mounds were identified from the difference map and labeled sequentially in Figure 8. The latitude and longitude of maximum elevation of each mound is given in Table 2.

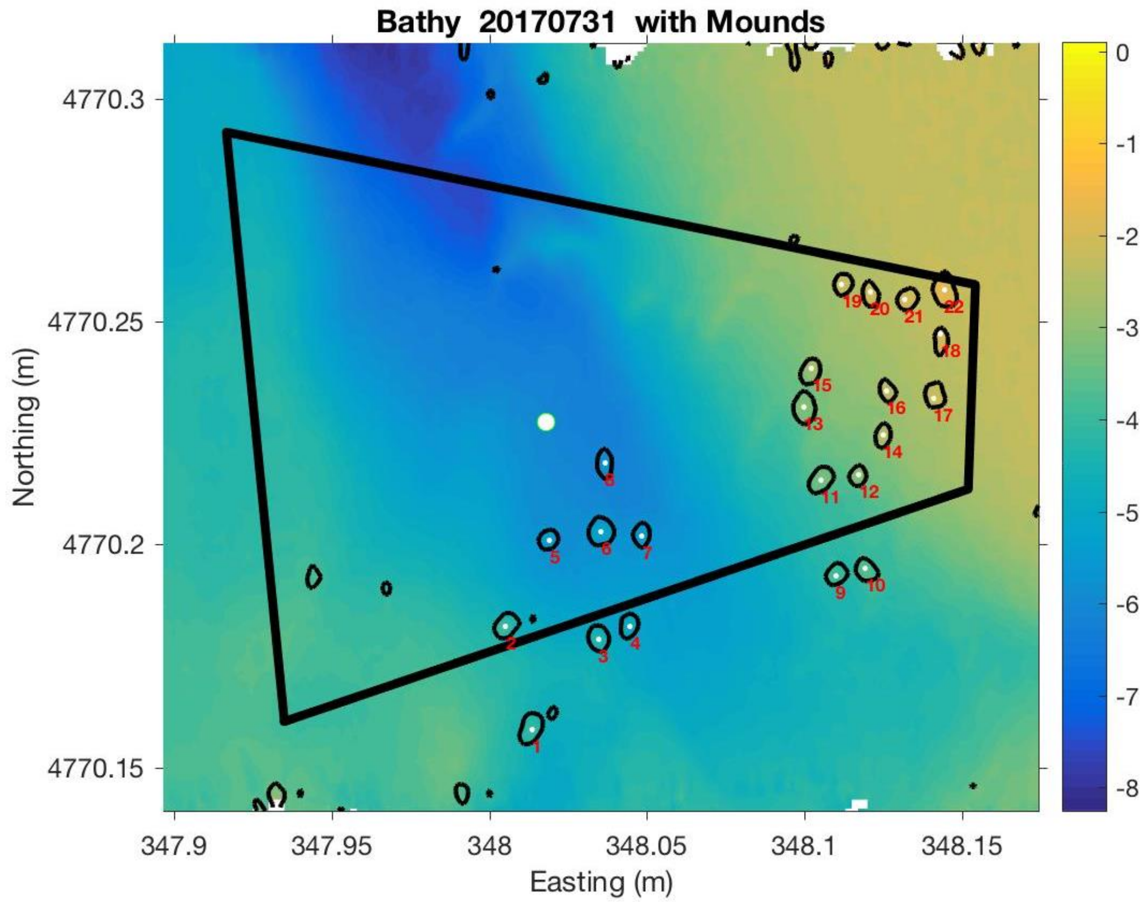


Figure 8. Bathymetric map from 31 July 2017 showing the outlined regions of the oyster mounds identified by the difference map (Figure 8). Locations of mound elevation maxima are indicated with white dots within the contours. Mounds are numbered from 1 to 22. Background bathymetry has 1.0 *m* resolution. Elevations are in *m* relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-hand-side. Horizontal coordinates are *km* in eastings and northings. The solid black line outlines the region encompassing the 5-acre artificial oyster reef region. White dot indicates the location of the ADCP deployed in 2018.

Subsequent surveys over the next 2 years (Table 1) monitored the deployed shell mounds. Changes in the elevation in the east-west direction across the center of each mound were determined from each survey at 0.25 *m* resolution. The profiles extend 10 *m* to the east and west of each mound center, and were smoothed with a 4-point median filter to remove small scale uncertainty from the survey (with 5-10 *cm* vertical resolution). Results from all surveys are shown Figure 9. Some locations show changes to the seafloor profile across the mounds that exceed the resolution of the survey and may be due to currents in the area, settling of the shell through time, ice gauging, growth of seaweed, or siltation. However, in general, the mounds did not significantly evolve over the 2.5 year period after deployment that included two winter icing periods.

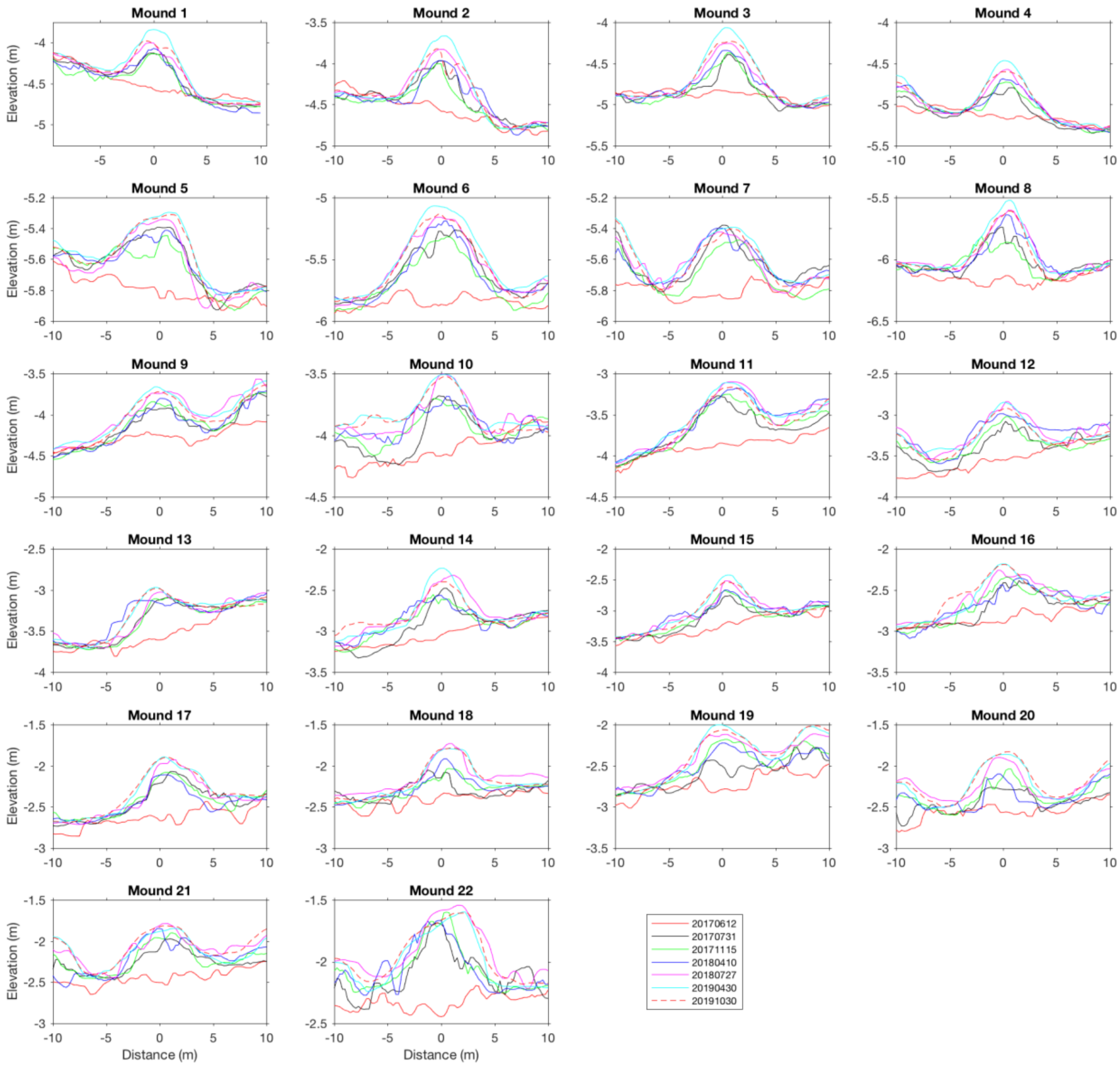


Figure 9. Bathymetric elevation profiles (in *m* relative to NAVD88) across all mounds at the Nannie Island restoration site. Survey dates are indicated in the legend. Horizontal axis is distance in *m* along an east-west transect relative to the center of the mound identified from the 31 July 2017 survey. All mounds were identified and show little change in all surveys after deployment of shell in the summer of 2017.

Table 2. Latitude and longitude of the 22 identified oyster reef mounds at Nannie Island.

Mound number	Latitude (N)	Longitude (E)
1	43.06891	-70.86674
2	43.06912	-70.86685
3	43.06910	-70.86648
4	43.06913	-70.86636
5	43.06930	-70.86668
6	43.06932	-70.86648
7	43.06931	-70.86632

8	43.06945	-70.86647
9	43.06924	-70.86556
10	43.06926	-70.86545
11	43.06943	-70.86563
12	43.06945	-70.86548
13	43.06958	-70.86570
14	43.06953	-70.86539
15	43.06966	-70.86567
16	43.06962	-70.86538
17	43.06961	-70.86519
18	43.06974	-70.86517
19	43.06983	-70.86556
20	43.06982	-70.86545
21	43.06980	-70.86531
22	43.06983	-70.86516

Currents Observed at Nannie Island

Water levels, current speeds, and current directions (Figure 10) observed in the approximate center of the Nannie Island site (e.g., location shown in Figure 8) over a 40 day period from 11 July 2018 through 20 August 2018 with a refurbished Nortek AWAC acoustic Doppler current profiler (ADCP). These data provide a measure of the typical velocity magnitude near the center of the reef, which reach 50 *cm/s* during spring tides. The lack of change to the character of the oyster mounds suggests that currents of this magnitude are not strongly affecting the evolution of the artificial oyster mounds. These data can be used for modeling studies that may include, for example, larval dispersion or sedimentation, each relevant to the viability of oyster populations and health.

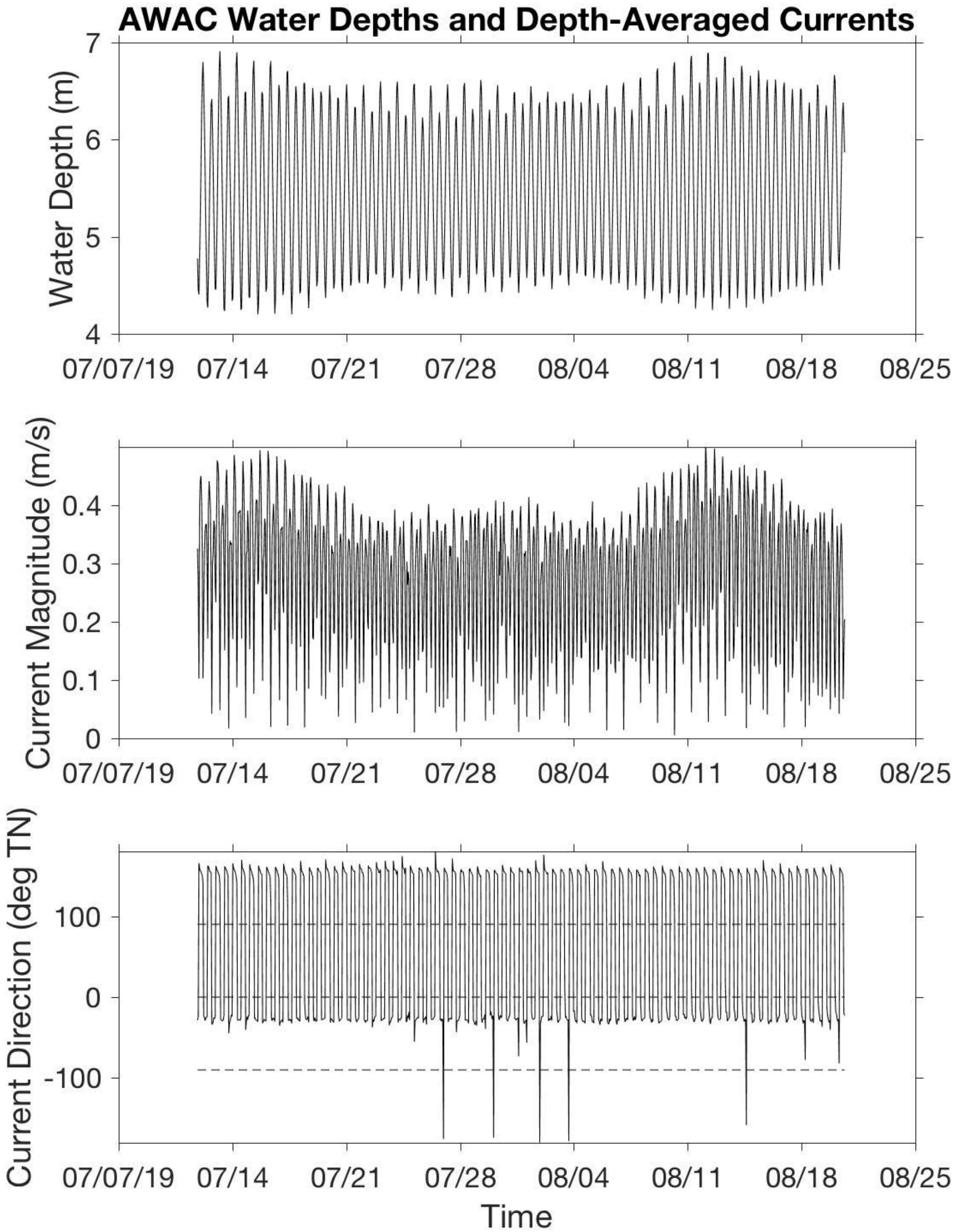


Figure 10. Water levels (top), depth-averaged current magnitude (center), and depth-averaged current direction (bottom) obtained from a bottom-mounted ADCP over a 40 day period in 2018 in the center of the Nannie Island restoration site. Maximum speeds reach 50 *cm/s* during spring tide periods. Currents are strongly controlled and polarized by the tides with 1.7 – 2.7 *m* tidal elevation swing.

Woodman Pt.

The bathymetric maps with 25-100 *cm* horizontal resolution were obtained at the Woodman Pt. restoration site (Figure 2) beginning on 09 May 2018 (prior to shell deployment). Survey methods for the Woodman Pt. site are identical to those employed at Nannie Island (discussed above). Table 1 outlines the timeline of the surveys that were conducted.

Bathymetric maps obtained 09 May and 16 September 2018 (bracketing the deployment of shell in August 2018) are shown in Figures 11 and 12, respectively. The difference map obtained by subtracting the first survey from the second is shown in Figure 13, and reveals the presence of 14 identifiable mounds. Contour methods developed as part of the Nannie Island efforts were employed here. The identified mounds are shown with contours in Figure 14, with each numbered sequentially. The latitude and longitude of the mound locations are listed in Table 3. Figure 15 shows the evolution of mound profiles (similar to that shown in Figure 9 for Nannie Island). The mounds did not evolve significantly over the 1.25 year monitoring period.

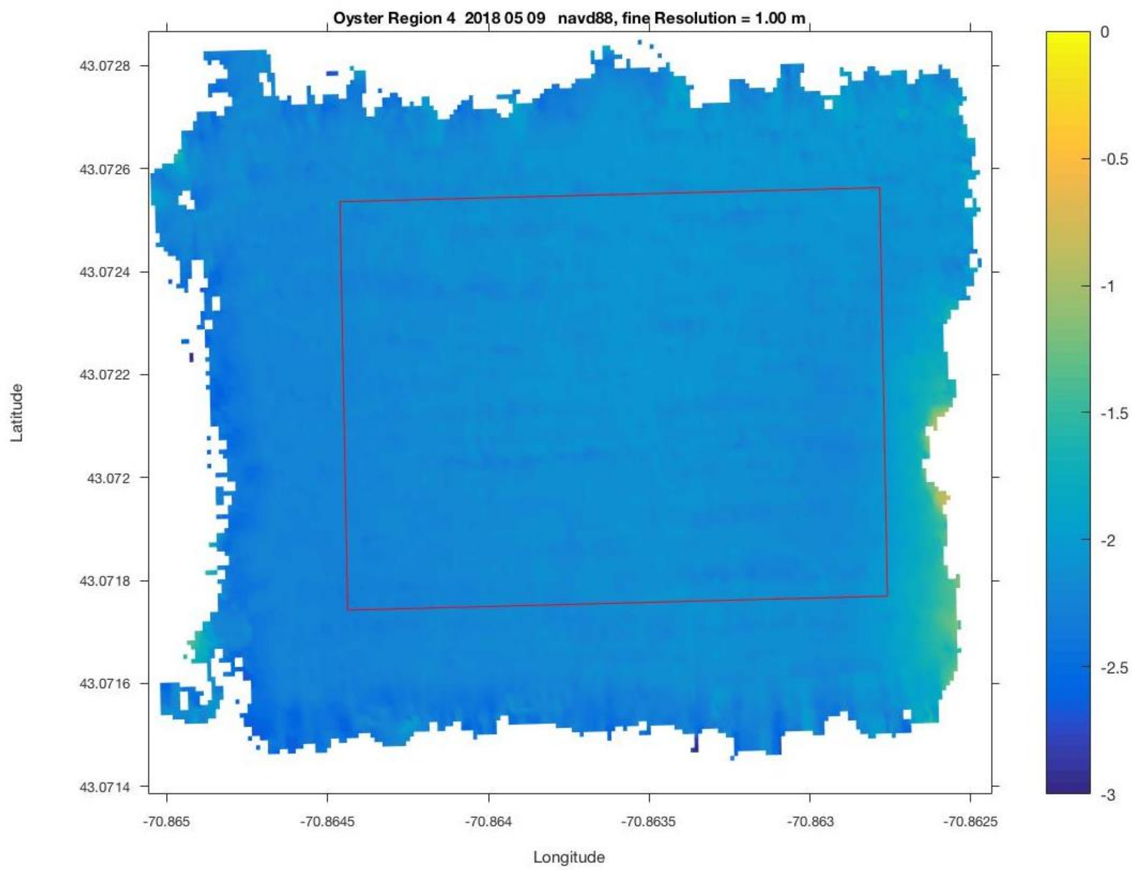


Figure 11. Bathymetric map of the restoration site at Woodman Pt. conducted on 09 May 2018. Horizontal resolution is 100 *cm*. Elevations are in *m* relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-hand-side. Horizontal coordinates are east longitude (*deg*) and north latitude (*deg*). The solid red line outlines the region encompassing the targeted artificial oyster reef region.

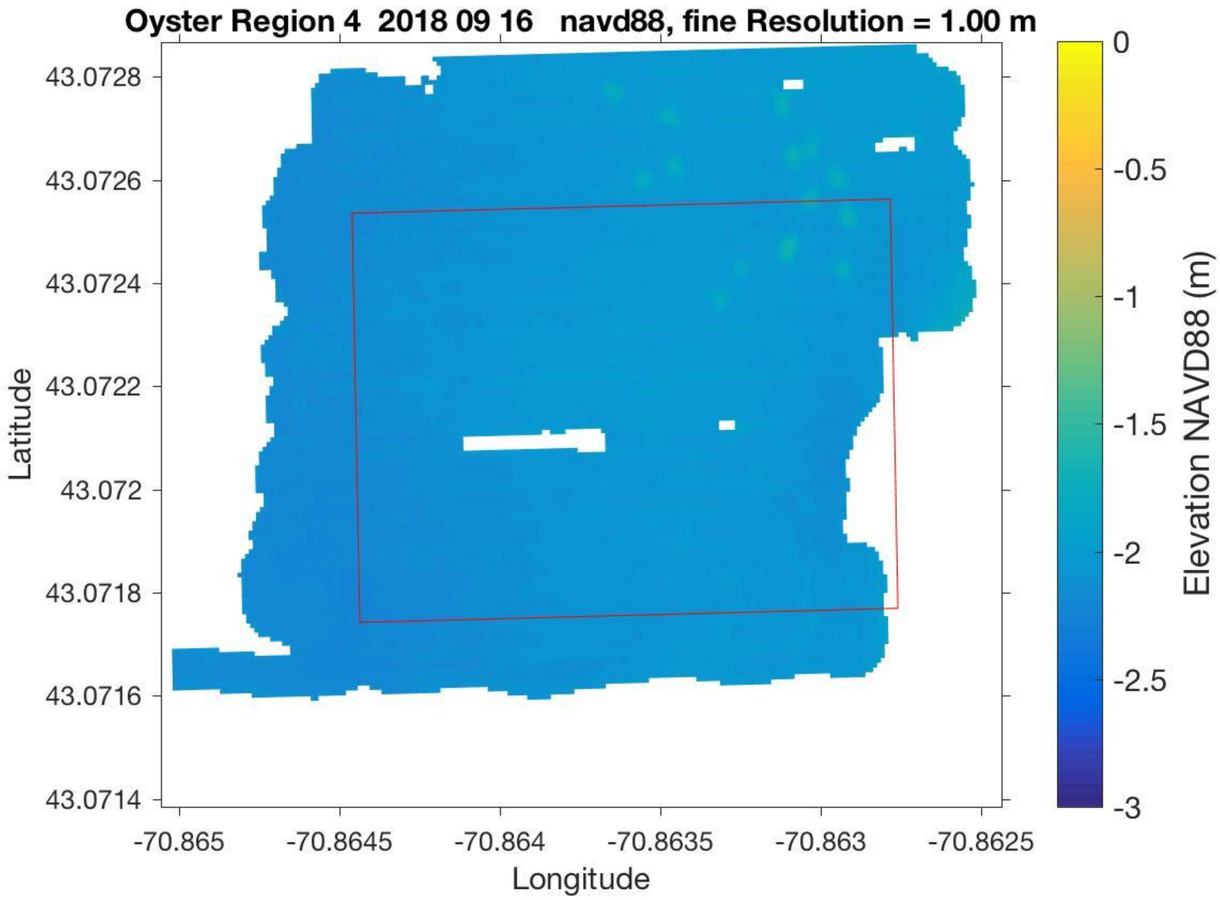


Figure 12. Bathymetric map of Woodman Pt. obtained on 16 September 2018. Horizontal resolution is 100 *cm*. Elevations are in *m* relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-hand-side. Horizontal coordinates are east longitude (*deg*) and north latitude (*deg*). The solid red line outlines the region encompassing the targeted artificial oyster reef region. The location of artificial mounds is evident in the upper right corner of the region.

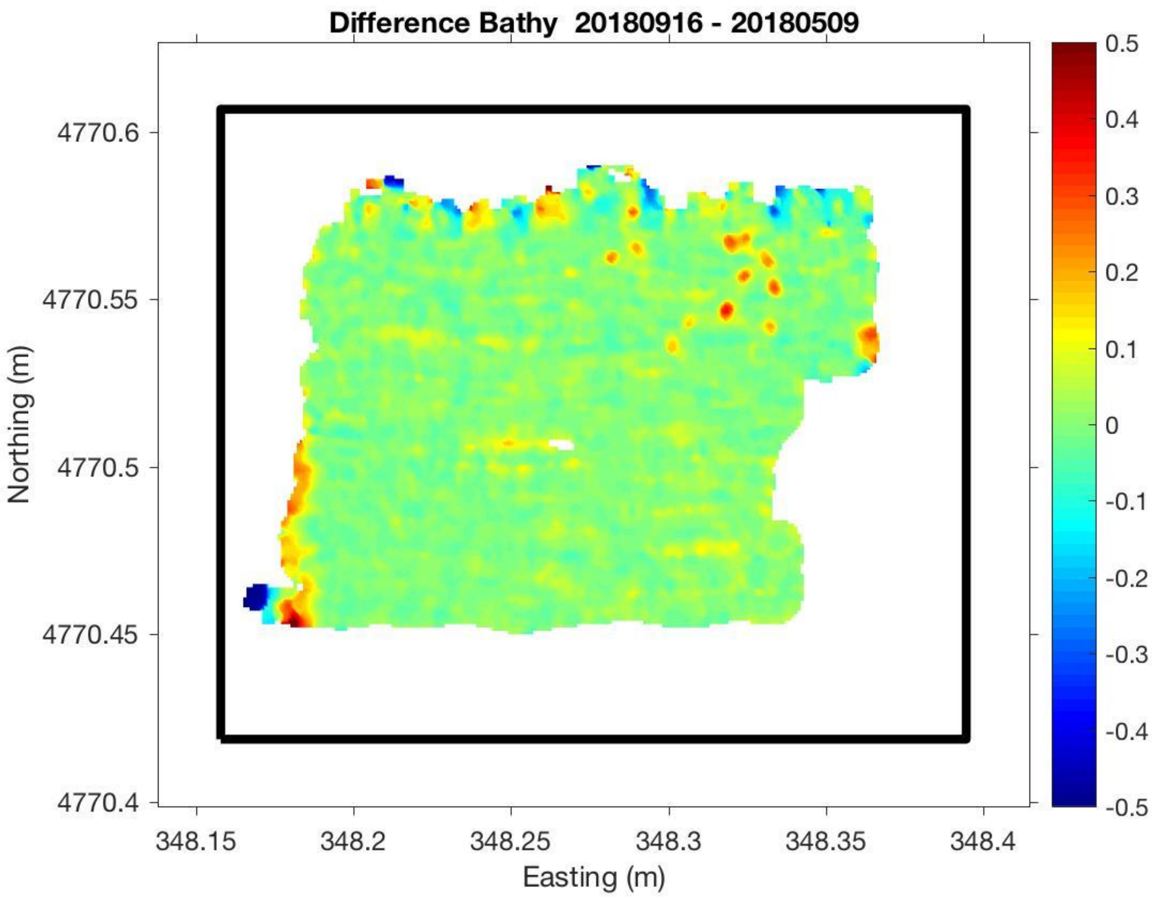


Figure 13. Difference elevation map for Woodman Pt. between initial survey conducted on 09 May 2018 and post-deployment survey conducted on 16 September 2018. Locations of deployed oyster shells are easily identified by elevated mounds (reddish colors). Horizontal resolution is 100 *cm*. Elevation differences are in *m* and given by the colorbar on the right-hand-side. Horizontal coordinates are *km* in eastings and northings.

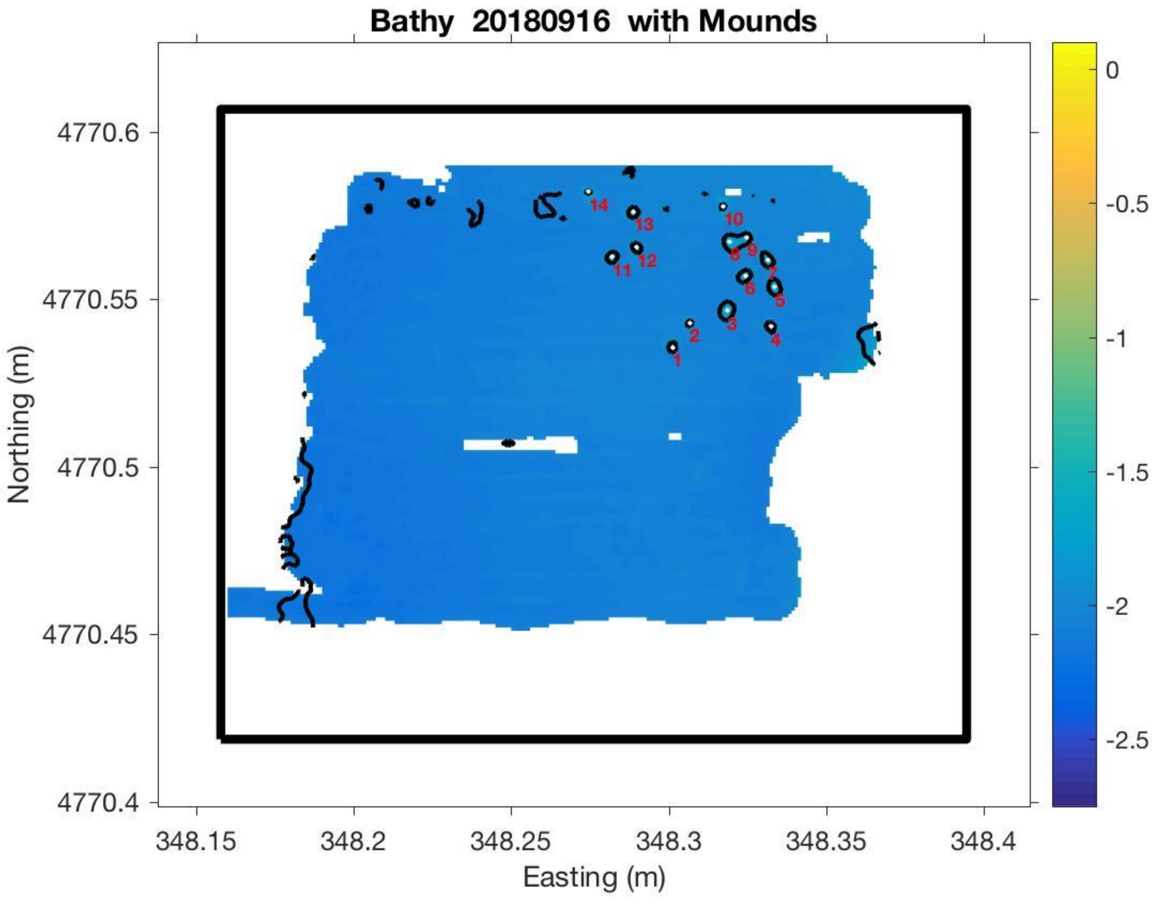


Figure 14. Bathymetric map of Woodman Pt. obtained on 16 September 2018 also showing the outlined regions of the oyster mounds identified by the difference map (Figure 13). Locations of mound elevation maxima are indicated with white dots within the contours. Mounds are numbered from 1 to 14. Background bathymetry has resolution of 1.0 *m*. Elevations are in *m* relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-hand-side. Horizontal coordinates are *km* in eastings and northings.

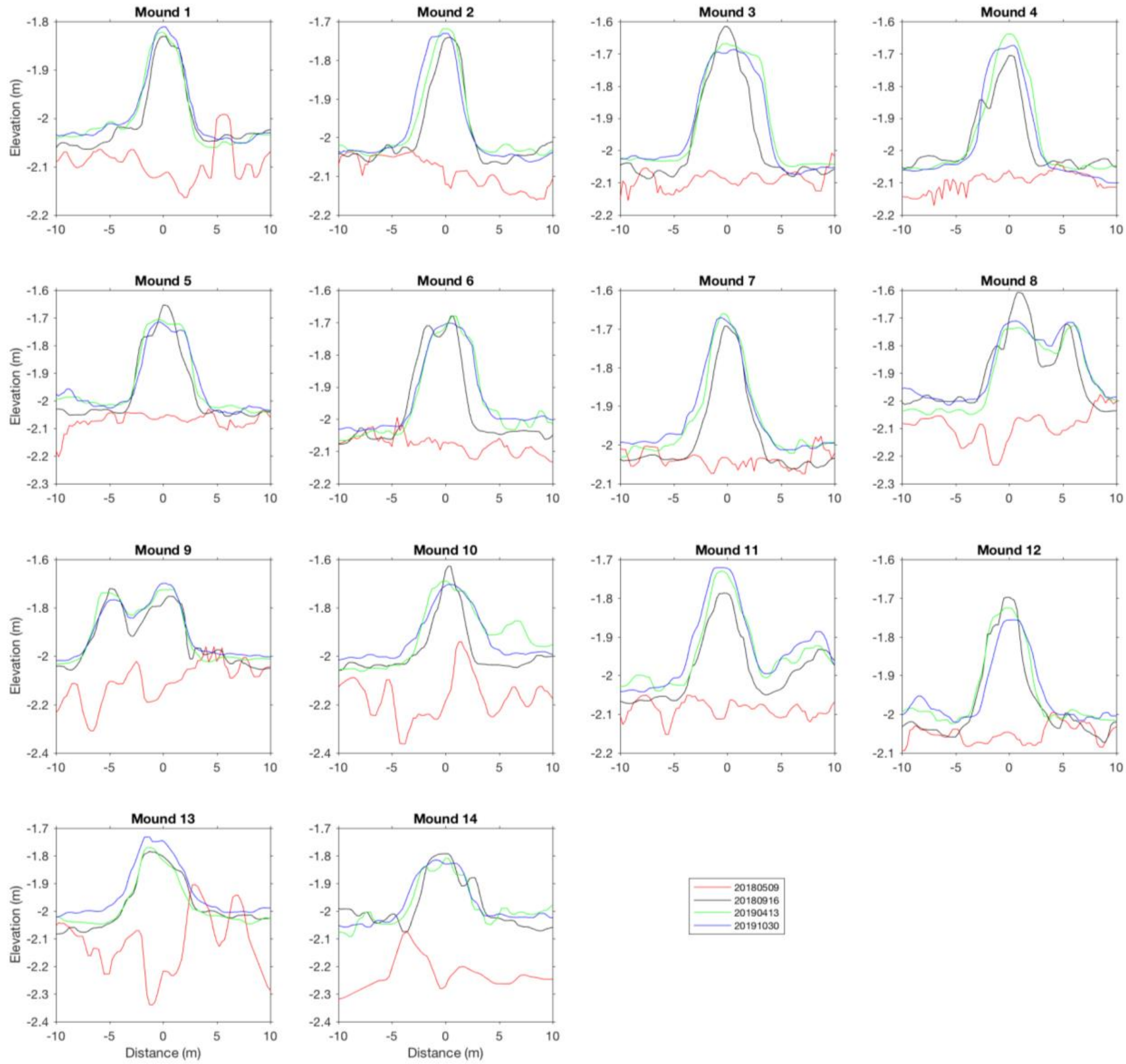


Figure 15. Bathymetric elevation profiles (in *m* relative to NAVD88) across all mounds for Woodman Pt. Survey dates are indicated in the legend. Horizontal axis is distance in *m* along an east-west transect relative to the center of the mound identified from the 16 Sep 2018 survey. All mounds (1-14) show little change over the 1.25 year monitoring period.

Table 3. Latitude and longitude of the 14 identified oyster reef mounds at Woodman Pt.

Mound number	Latitude (N)	Longitude (E)
1	43.07236	-70.86331
2	43.07243	-70.86324
3	43.07247	-70.86310
4	43.07243	-70.86293
5	43.07253	-70.86292
6	43.07256	-70.86303
7	43.07260	-70.86295
8	43.07265	-70.86309
9	43.07266	-70.86303
10	43.07275	-70.86312
11	43.07260	-70.86355
12	43.07263	-70.86346
13	43.07273	-70.86347
14	43.07278	-70.86365

Lamprey Restoration Sites

Bathymetric maps with 25-100 *cm* horizontal resolution were obtained at 2 sites near the Lamprey River (Figure 2), denoted herein as north and south, beginning on 09 May 2018 prior to shell deployment in August 2018. Survey methods for these sites are identical to those employed at Nannie Island and Woodman Pt. (discussed above). Table 1 outlines the timeline of the surveys that were conducted.

Bathymetric maps obtained 09 May and 16 September 2018 (bracketing the deployment of shell in August 2018) are shown in Figures 16 and 17, respectively. The difference map obtained by subtracting the first survey from the second is shown in Figure 18 for each site. For the Lamprey south site, the difference map reveals the presence of 10 identifiable mounds. However, the evolution of the bathymetry or low relief of the deployed shell mounds at the north site precluded confident extraction of oyster mounds there. The identified mounds from the Lamprey south site are shown with contours in Figure 19, with each numbered sequentially. The latitude and longitude of the mound locations are listed in Table 4. Figure 20 shows the evolution of mound profiles (similar to that shown in Figure 9 for Nannie Island and Figure 15 for Woodman Pt.). Once again, the mounds were not observed to evolve significantly over the 1.25 year monitoring period. No profiles are shown for the Lamprey north region as the mounds were not robustly identified.

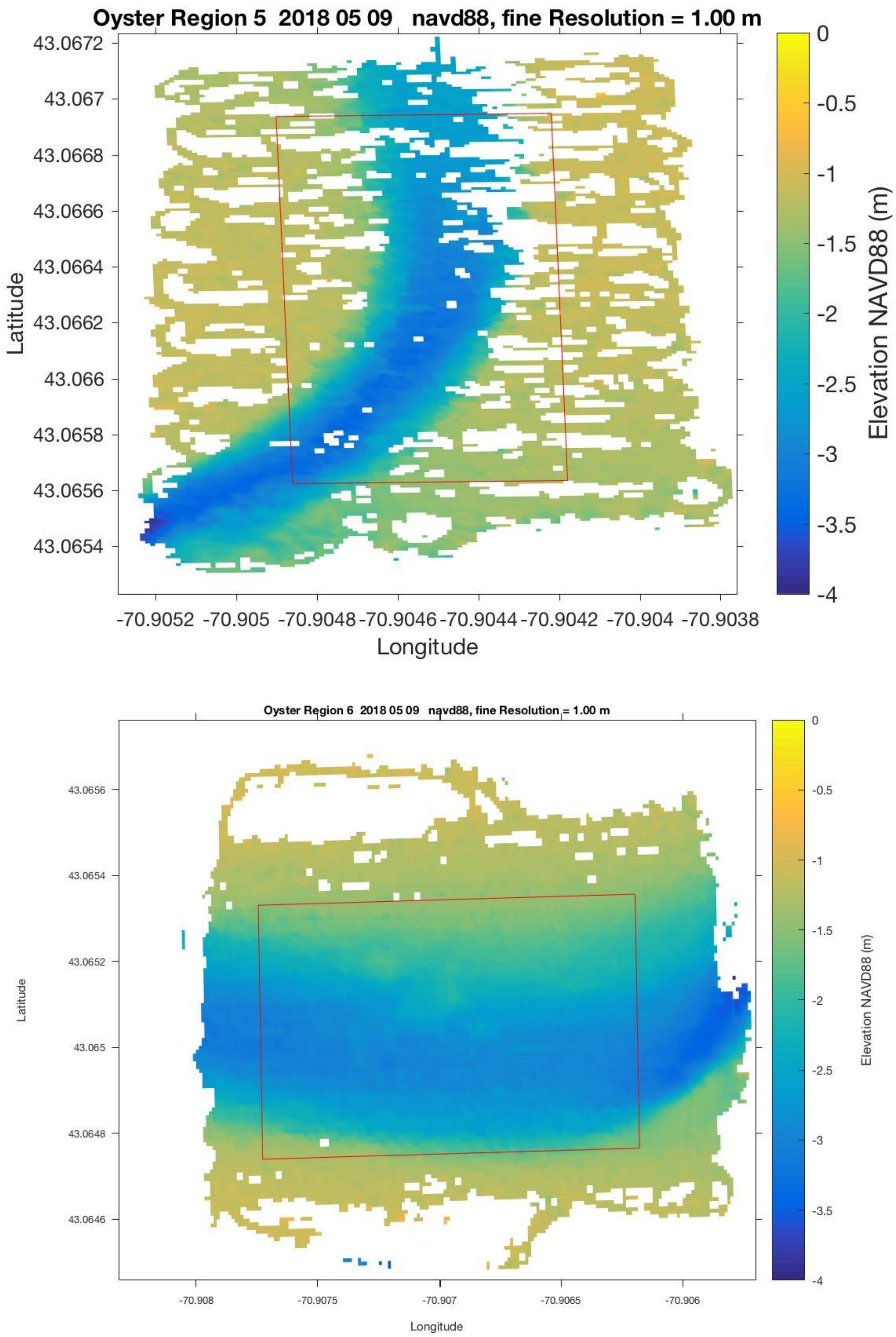
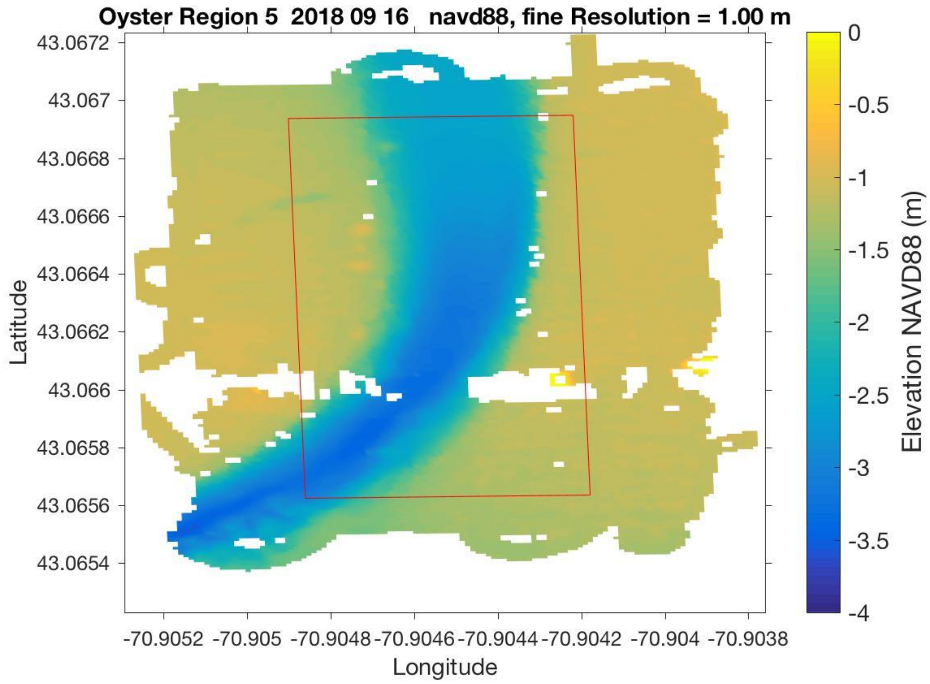


Figure 16. Bathymetric maps of the Lamprey River restoration sites conducted on 09 May 2018. (top) 1 acre Lamprey north. (bottom) 2 acre Lamprey south. Horizontal resolution is 100 *cm*. Elevations are in *m* relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-hand-side. Horizontal coordinates are east longitude (*deg*) and north latitude (*deg*). The solid red line outlines the region encompassing the artificial oyster reef region.



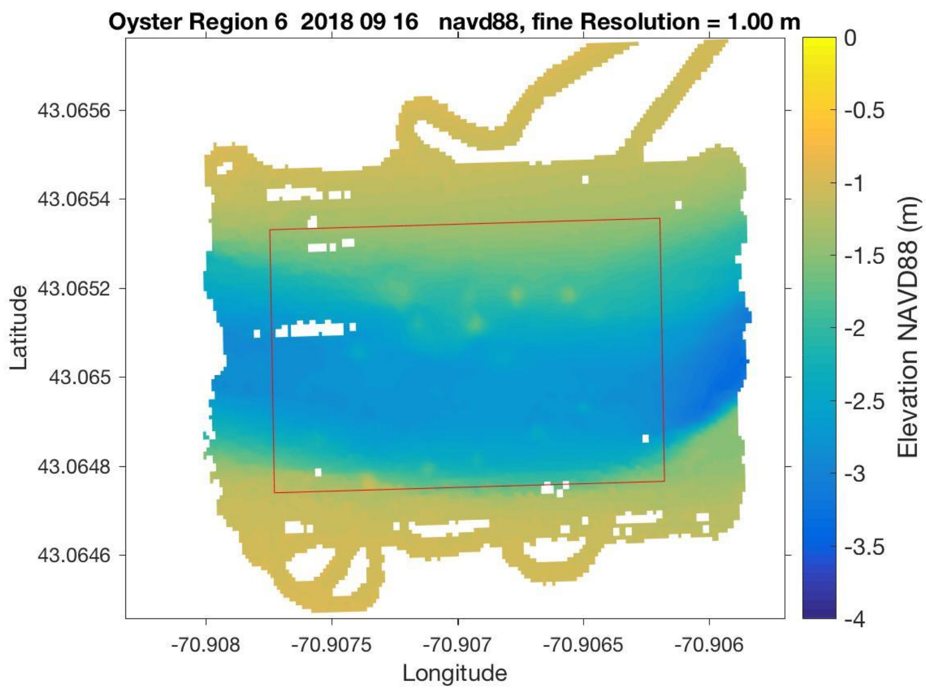


Figure 17. Bathymetric maps of Lamprey north (top) and Lamprey south (bottom) restoration sites conducted on 16 September 2018. Horizontal resolution is 100 *cm*. Elevations are in *m* relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-hand-side. Horizontal coordinates are east longitude (*deg*) and north latitude (*deg*). The solid red line outlines the region encompassing the artificial oyster reef region.

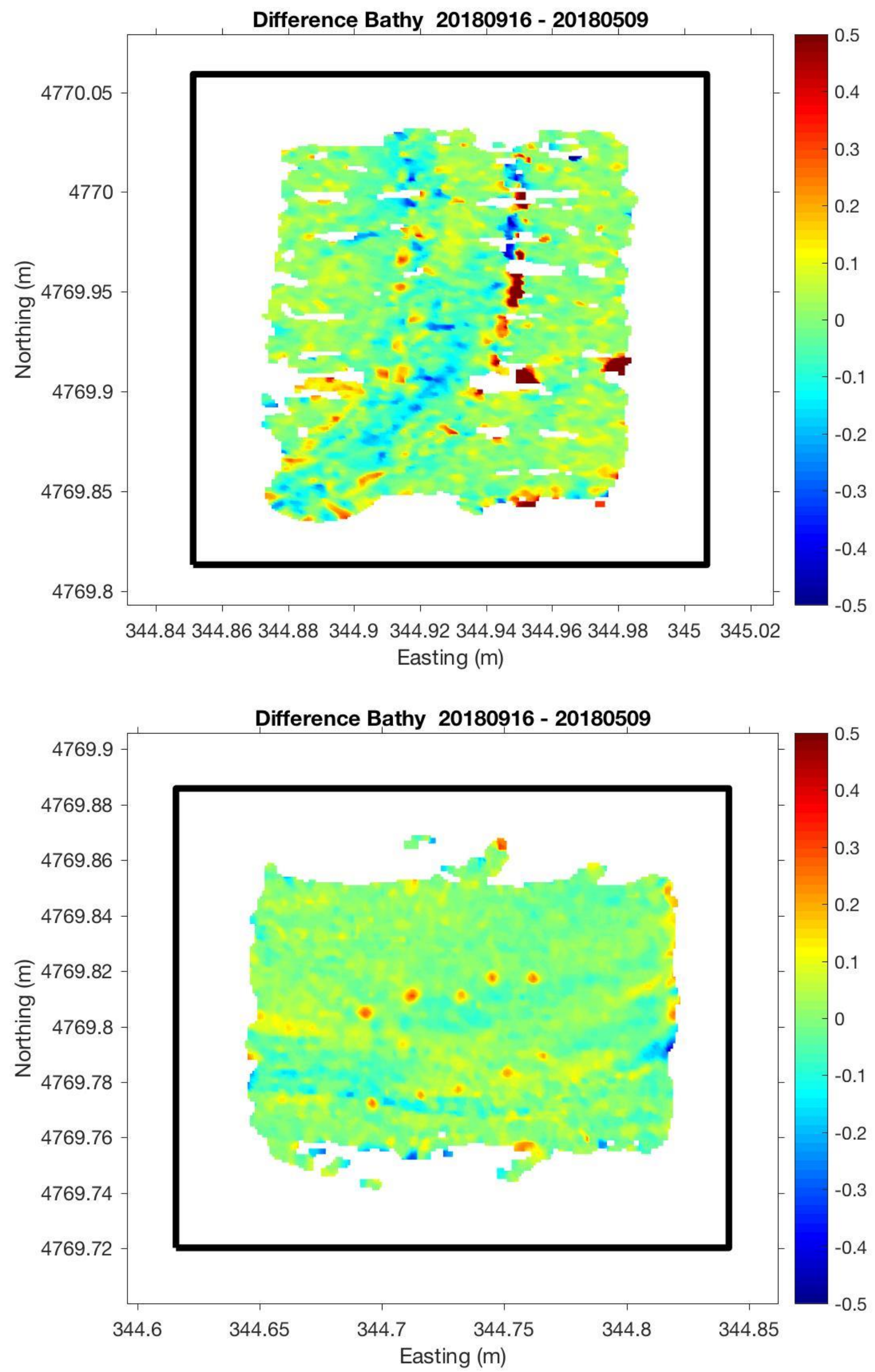


Figure 18. Difference elevation maps between initial surveys conducted on 09 May 2018 and surveys conducted on 16 September 2018. Locations of deployed oyster shells are easily identified by elevated mounds (reddish colors) at the Lamprey south (bottom) difference map. However, differences for the Lamprey north (top) region are much more difficult to discern. Horizontal resolution is 100 *cm*. Elevation differences are in *m* and given by the colorbar on the right-hand-side. Horizontal coordinates are *km* in eastings and northings.

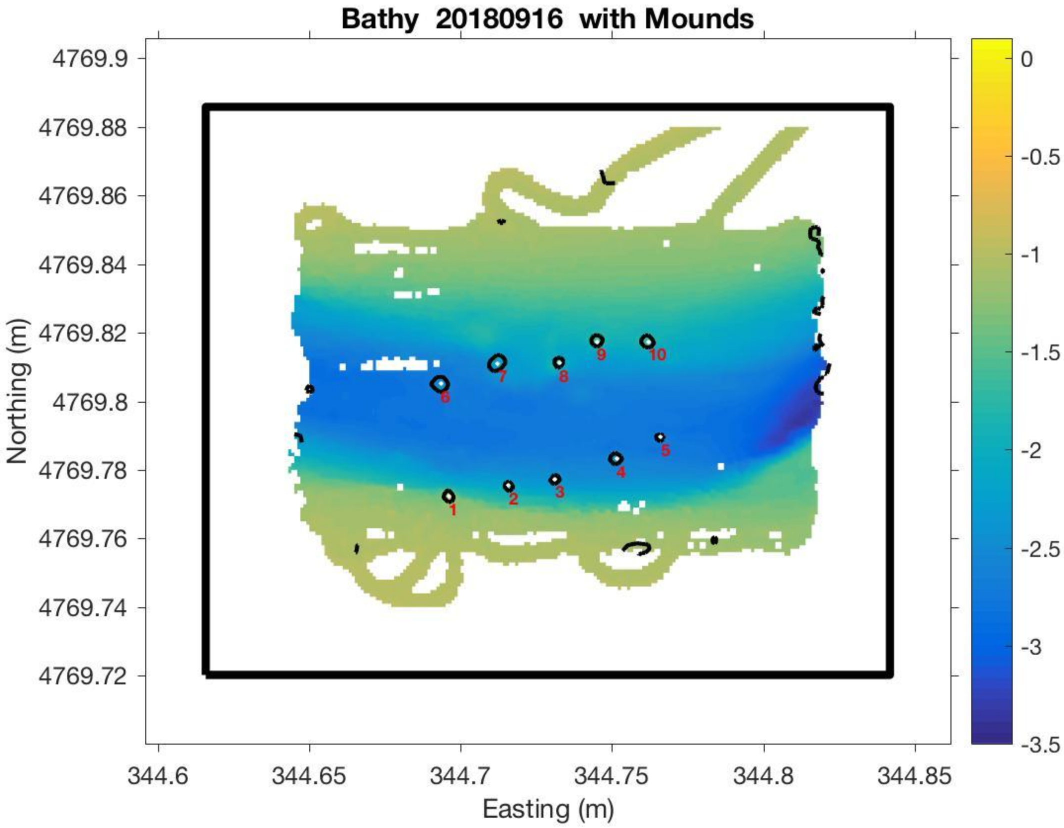


Figure 19. Bathymetric maps of Lamprey north (top) and Lamprey south (bottom), each from 16 September 2018. Outlined regions of the oyster mounds identified by the difference map for Lamprey south are indicated by the white dots at each mound elevation maxima and are numbered from 1 to 10. Background bathymetry has resolution of 1.0 *m*. Elevations are in *m* relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-hand-side. Horizontal coordinates are *km* in eastings and northings.

Table 4. Latitude and longitude of the 10 identified oyster reef mounds at Lamprey south.

Mound number	Latitude (N)	Longitude (E)
1	43.06477	-70.90735
2	43.06480	-70.90711
3	43.06482	-70.90692
4	43.06487	-70.90668
5	43.06493	-70.90650
6	43.06506	-70.90740
7	43.06512	-70.90717
8	43.06512	-70.90692
9	43.06518	-70.90677
10	43.06518	-70.90656

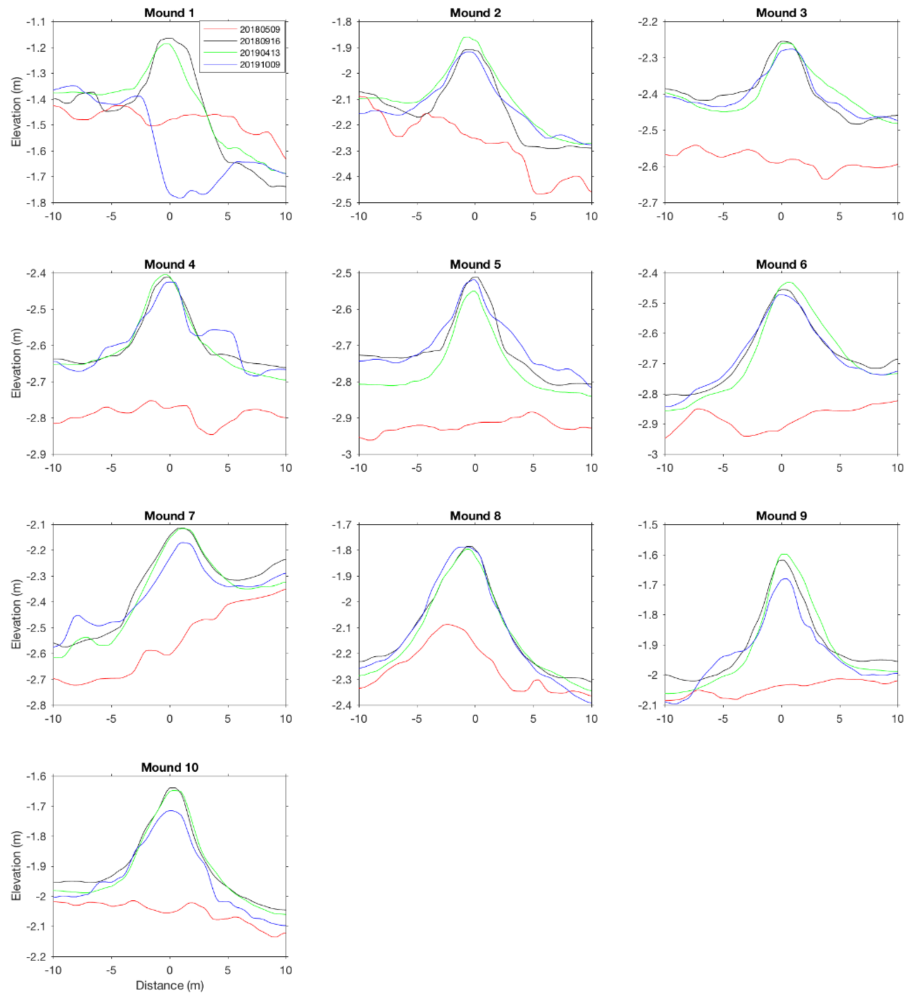


Figure 20. Bathymetric elevation profiles (in *m* relative to NAVD88) across all mounds for Lamprey south. Survey dates are indicated in the legend of mound 1. Horizontal axis is distance in *m* along an east-west transect relative to the center of the mound identified from the 16 Sep 2018 survey. Mounds 2-10 show little change. Note that mound 1 was removed in the summer of 2019.

During the summer of 2019, 3 mounds at the Lamprey restoration sites were eliminated owing to concern over navigation safety. The changes in these areas are readily seen in the difference bathymetry maps for both the southern and northern Lamprey regions (Figures 21 and 22, respectively). For the Lamprey north site (Figure 21), there was significant change to the bathymetry showing some silting in of the tidal channel. Also, readily evident is the 2 large erosional spots (dark blue blobs) resulting from the removal of artificial mounds (or at least excavation of the material in those locations). Similarly, for the Lamprey south site, the difference map (Figure 22) shows the clear removal of one mound. The profiles across mound 1 (Figure 20) clearly shows the removal of the material.

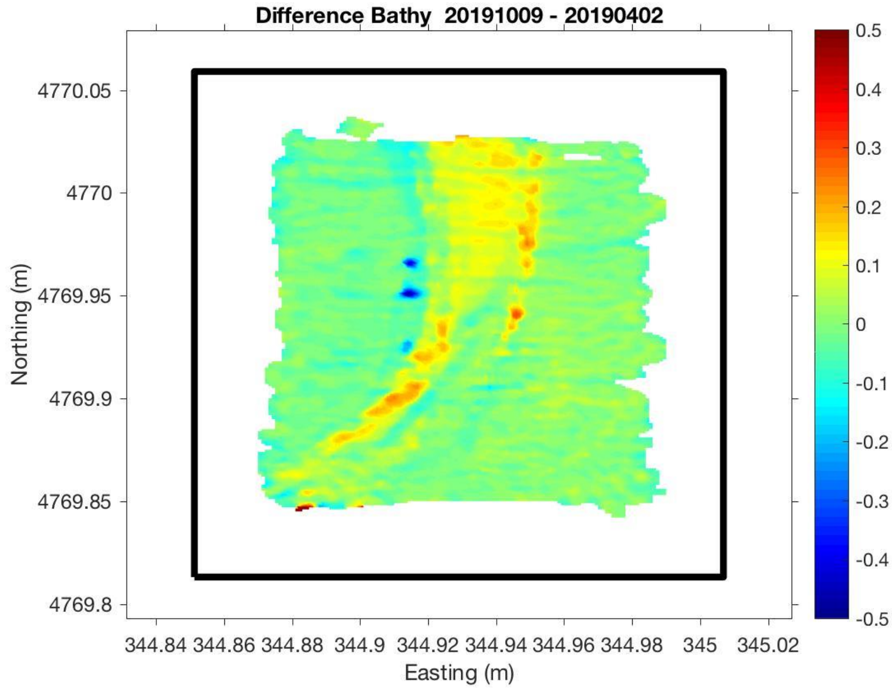


Figure 21. Difference map between surveys conducted on 02 Apr 2019 and 09 Oct 2019 at the Lamprey north site. The dark blue blobs show the location of the mounds that were manually removed in the summer of 2019.

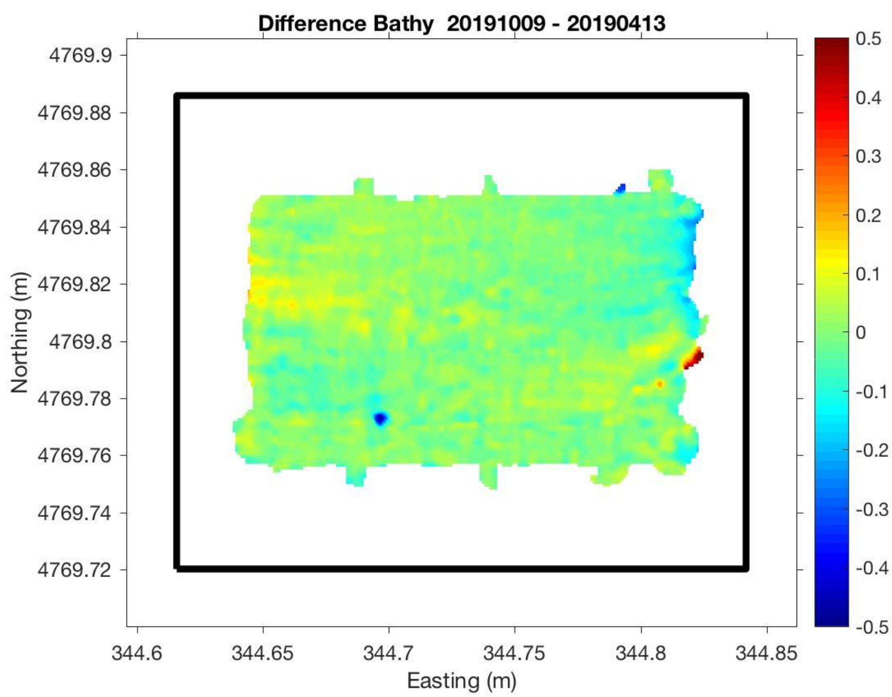


Figure 22. Difference map between surveys conducted on 02 Apr 2019 and 09 Oct 2019 at the Lamprey south site. The dark blue blob shows the location of mound 1 that was manually removed in the summer of 2019.

Natural Reef Surveys: Oyster River, Lamprey River, Nannie Island, Adam's Pt.

Surveys were obtained over the natural reefs at Nannie Island, Lamprey River, Oyster River, and Adam's Pt., and are shown in Figure 23-26, respectively. These bathymetric surveys over existing natural oyster reefs at Nannie Island, Oyster River, and Lamprey River were conducted in support of sediment vibra-coring by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Services (NRCS). An additional survey was conducted over the Adam's Pt. restoration site in support of ongoing work by collaborators (Dr. Grizzle, UNH) related to that site. The surveys provide a base, high-resolution map for each site, and constitute a starting point from which other subsequent surveys can be conducted to detect bathymetric change in the area or identification of new shell deployments that may occur in the future.

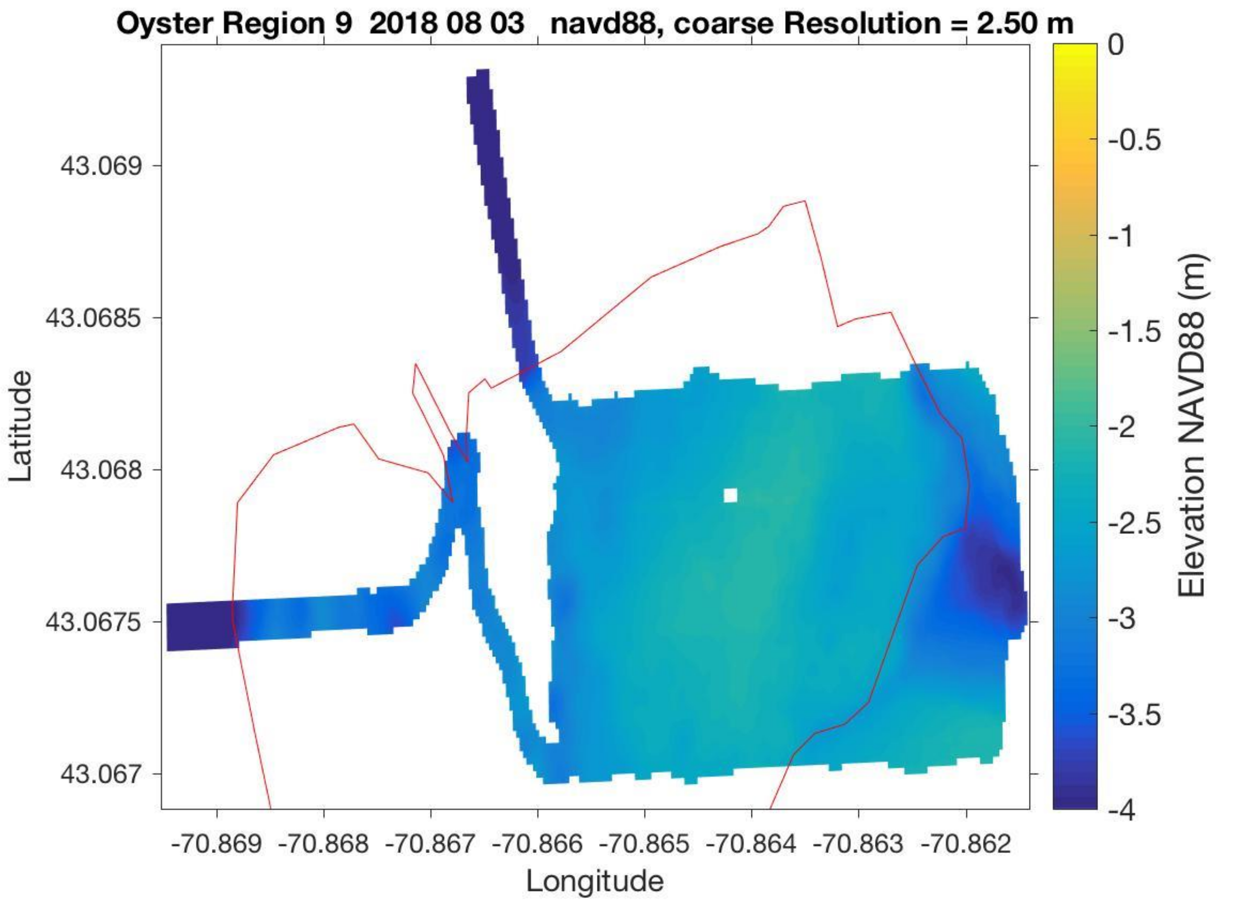


Figure 23. Bathymetric maps of the natural reef at Nannie Island conducted on 03 August 2018. Elevations are in *m* relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-hand-side. Horizontal coordinates are east longitude (*deg*) and north latitude (*deg*). The solid red line outlines the region encompassing the natural oyster reef region.

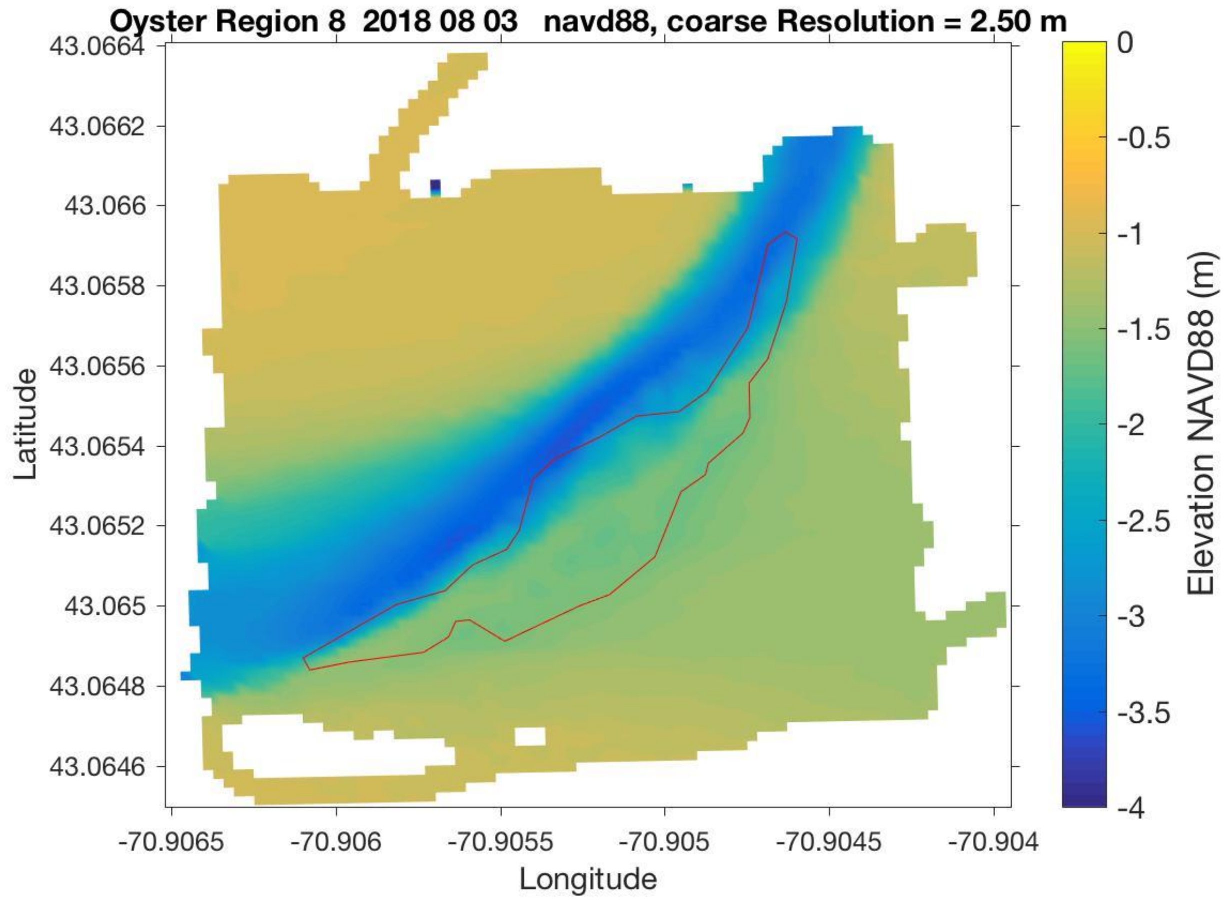


Figure 24. Bathymetric maps of the Lamprey River natural reef conducted on 03 August 2018. Horizontal resolution is 2.5 *m*. Elevations are in *m* relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-hand-side. Horizontal coordinates are east longitude (*deg*) and north latitude (*deg*). The solid red line outlines the region encompassing the natural oyster reef region.

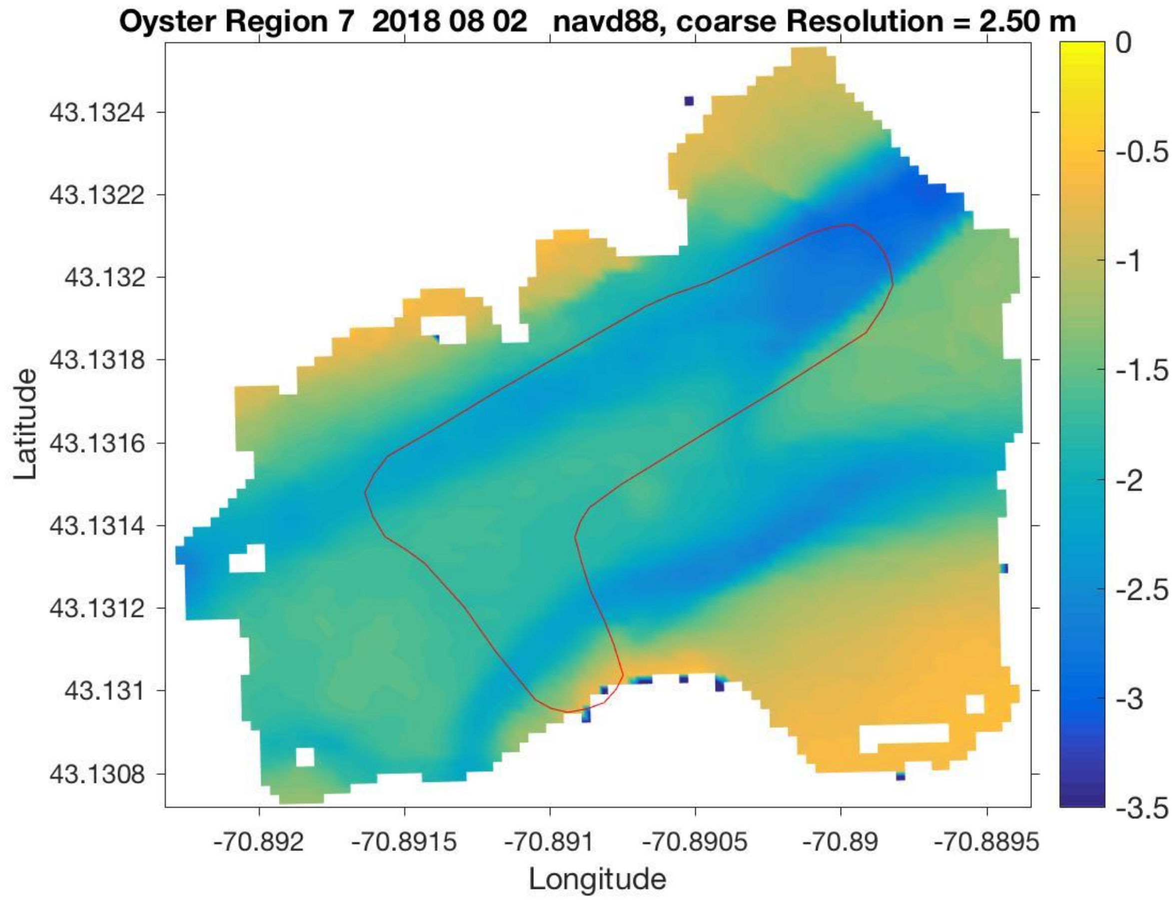


Figure 25. Bathymetric maps of the Oyster River natural reef regions conducted on 02 August 2018. Horizontal resolution is 2.5 *m*. Elevations are in *m* relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-hand-side. Horizontal coordinates are east longitude (*deg*) and north latitude (*deg*). The solid red line outlines the region encompassing the natural oyster reef region.

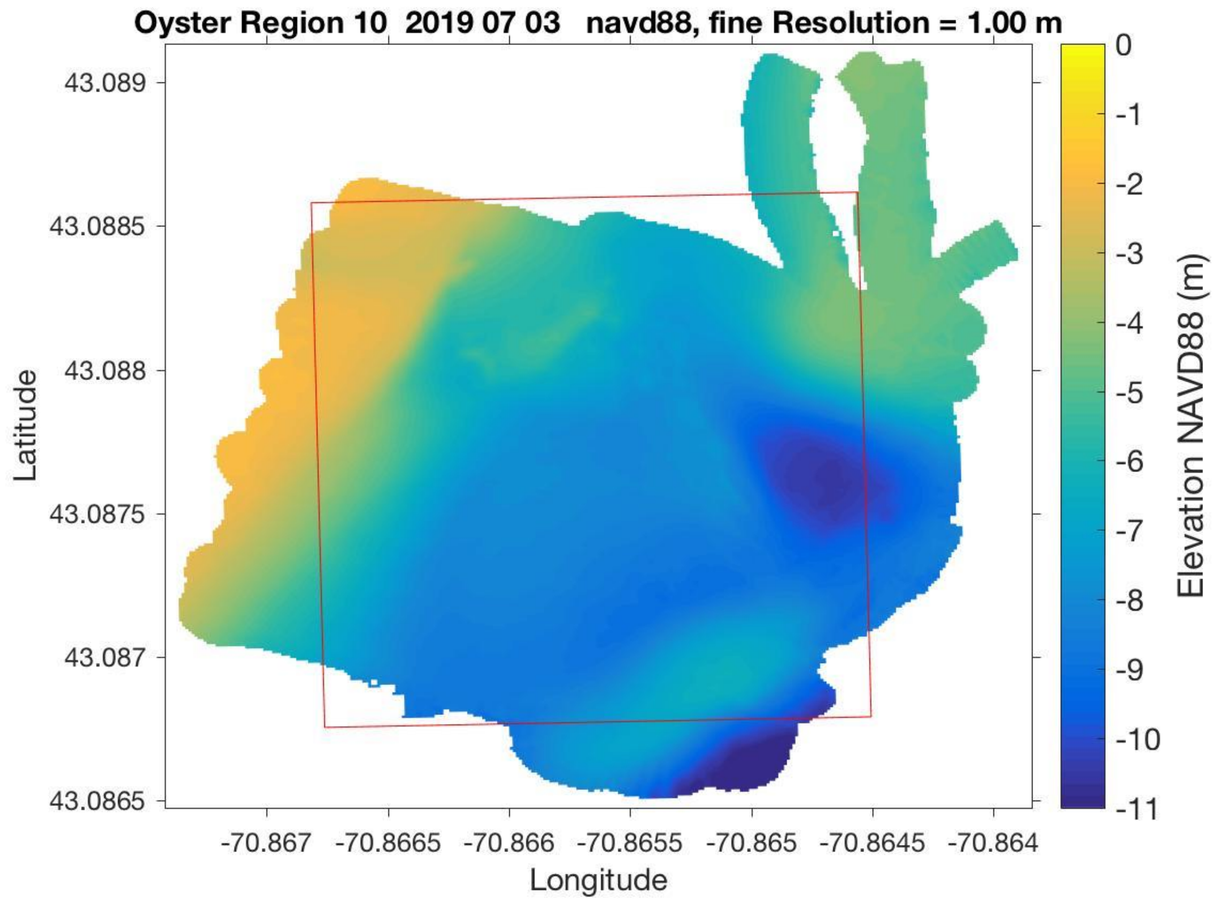


Figure 26. Bathymetric map of the Adam's Pt. bathymetric survey conducted on 03 July 2019. Horizontal resolution is 100 *cm*. Elevations are in *m* relative to NAVD88 (approximately mean sea level) and given by the colorbar on the right-hand-side. Horizontal coordinates are east longitude (*deg*) and north latitude (*deg*). The solid red line outlines the region encompassing the targeted survey region.

Backscatter Analysis

We analyzed field observations of acoustic backscatter sampled in the Great Bay Estuary (Figure 27) during the winter of 2015/2016. Sonar observations were obtained in water depths ranging 0.5–15 *m* along parallel transects separated by 25 *m* with an Odom Echotrac vertical-incidence dual frequency (200 and 24 *kHz*) single-beam echosounder mounted on a small vessel (the UNH R/V Galen J). Analysis is focused on the acoustic waveform envelope from each ping of the lower frequency signal (24 *kHz*). The ping rate was approximately 17-18 *Hz* resulting in a very large amount of acoustic response data.

Two analyses were pursued. In the first, principal components are computed using EOF decomposition of the entire waveform profiles of the 24 *kHz* signal. For each sonar ping, the waveform of the first interaction with the bottom was identified, and used in the decomposition of the data. This differs from previous efforts that focus on identifying parameters for each ping (such as mean intensity, maximum intensity, rise time, area, skewness, and kurtosis) of the higher

200 *kHz* signal. Significant volume scattering of the 24 *kHz* signal was too complex to identify parameters. The volume scattering also suggests that the 24 *kHz* signal penetrated the bed up to 5 *m* below the surface of the sediments indicating the analysis of this data should provide information of the character of the substrate. In the second, the structure of the backscatter intensity was examined by computing the average intensity over a given depth range within the substrate (from the seafloor to 5 *m* below the seafloor). These are each discussed in turn below.

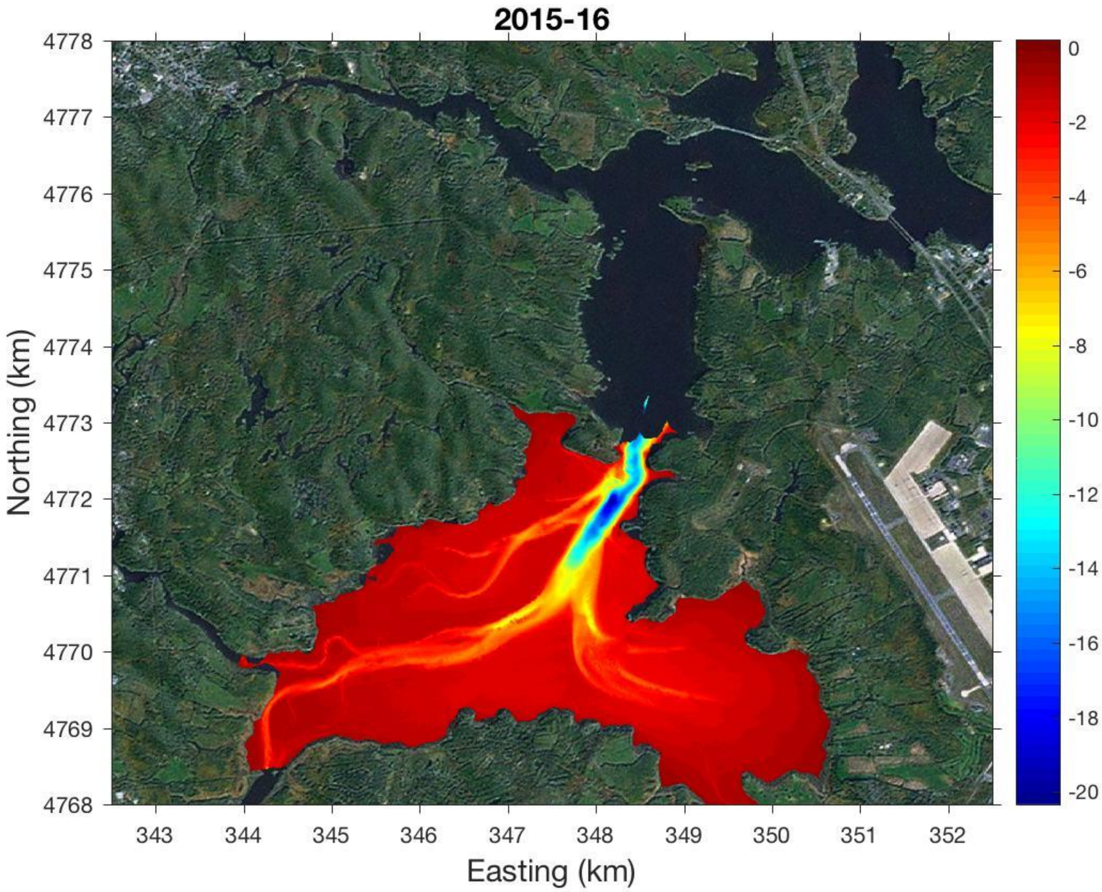


Figure 27. Bathymetry of the Great Bay Estuary sampled in 2015/16. Depths are in meters relative to NAVD88 (shown with the colorbar on the right hand side). Horizontal coordinates are UTM Eastings and Northings (in km).

EOF Decomposition of 24 kHz Acoustic Backscatter Analysis

The spatial variability in properties of the waveforms was decomposed into orthogonal eigenvectors using standard principle component (or EOF) analysis. This analysis of variance allow assessment for objective assessment of acoustic response to various bottom types useful for seafloor characterization studies.

EOF analysis is based on an eigenvector decomposition of a data covariance matrix into separate orthogonal components. Each component accounts for a specific amount of the variance, numbered sequentially from the first to last in descending order of variance. It is important to note that in this decomposition, each component is constrained to be orthogonal to the other components, making higher components more difficult to physically interpret. The components describe how a certain weighting of the original properties (described by the eigenvectors) varies spatially and is given by

$$X_m(v) = \sum_{k=1 \; to \; M} F_k(v) a_k(m) \qquad (1)$$

where $F_k(v)$ is the normalized PCA eigenfunction for component k as a function of variable v, $a_k(m)$ is the spatial weighting of the k^{th} component at position m, $X_m(v)$ are the observations of each variable v at spatial position m, and M is the total number of components (equal to the number of variables considered). The spatial variation (or weighting) of each PCA component, $a_k(m)$, is given by

$$a_k(m) = \sum_{v=1 \; to \; M} F_k(v) X_k(m) \qquad (2)$$

Analysis of 24 kHz acoustic waveforms

The acoustic waveform envelope – specifically defined in this study as the segment of the acoustic backscatter representative of the signal's first interaction with the bottom – is extracted from the full waveform and further analyzed. A statistical decomposition of the envelope's properties reveals spatial patterns in acoustic data that are dependent on bottom composition. Using principal component analysis to decompose envelope properties removes subjective biases and objectively produces factors that most efficiently represent the variance distribution of the data.

During field sampling in 2015/2016, sonar data and RTK-GPS GGA NMEA strings were recorded simultaneously in an ODOM *dso* file. The data from the *dso* files were parsed and the full waveforms digitally stored along with ancillary sonar settings, position, and time information. Each full return from the 200 *kHz* signal was interrogated based on a median intensity threshold to find and extract the portion of the backscatter representative of the first acoustic interaction with the bottom. Pings with erroneous depth or positions were filtered out. The depth estimate using the 200 *kHz* acoustic pulse much better determines the location of the seafloor as the higher frequency pulses do not penetrate far into the seafloor (roughly 1-2 *cm*). The level of the seafloor determined in this manner was used to identify the start of the 24 *kHz* acoustic signal. This lower frequency acoustic pulse (with longer wavelength) penetrates into the seabed several meters to a depth determined by the nature of the substrate, and scattering elements within the various bed layers. This process is called "volume scattering" and provides information in the backscattered waveform that can be examined to determine characteristics of the sedimentary material below the surface of the seabed.

Two approaches can be applied to examine the backscattered acoustic waveforms. The first examines specific properties, including rise time, width, mean, maximum, skewness, kurtosis, and area of the first interaction with the bottom. This is quite difficult with signals that contain high volume scattering like the 24 *kHz* signal, and was abandoned in our approach here. The second approach is to evaluate the entire waveform from first interaction with the bottom to some defined depth-of-penteration into the bed (taken herein to be 5 m based on subjective examination of the waveforms). This approach is advantageous as all characteristics of the waveform contribute to the principal component decomposition, with a characteristic waveform shape the defines the eigenvectors, $X_m(v)$, that have spatial weighting across the estuary, $a_k(m)$.

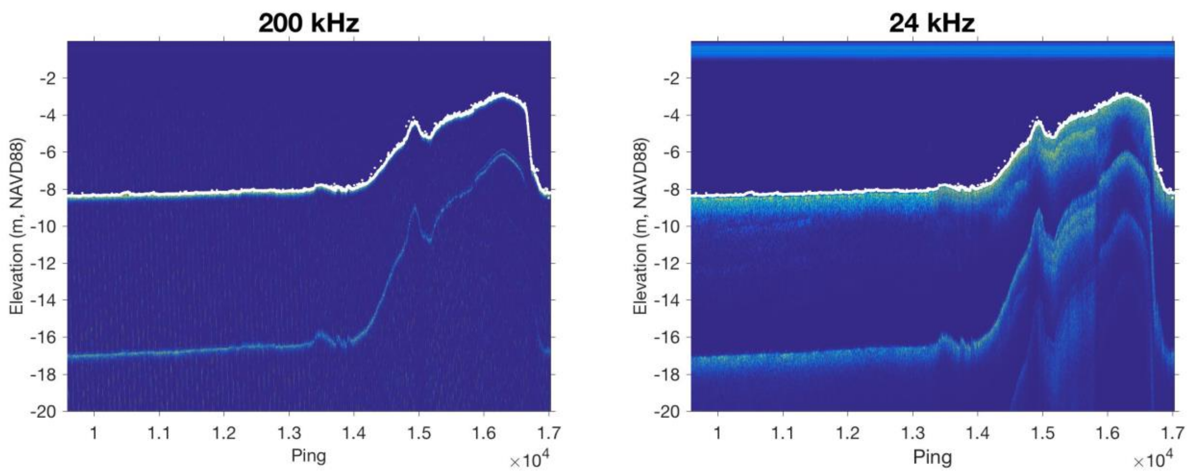


Figure 28. Color contours of acoustic waveform intensity for an example 16 minute record of 17,000 consecutive pings (at 17 Hz ping rate). Vertical axis is elevation relative to NAVD88 (in m) with the water surface at the time of data collection given by the top of the color-contoured regions. (left) 200 kHz signal. (right) 24 kHz signal. Location of the bottom determined with the 200 kHz signal is indicated with the white dots in each panel. The second reflection (echo) from the surface and back to the bottom is clearly visible at a depth twice that of the bottom. This second echo can be avoided by limiting the first waveform interaction with the bottom to a depth below the bed less than the depth of the seabed from the surface.

Figure 28 shows the backscatter intensity from the 200 and 24 *kHz* signals as a function of time (given as sequential ping) and distance below the water surface. The bottom depth is determined from the 200 *kHz* signal, and projected onto the 24 *kHz* signal to identify the start of the 24 *kHz* waveform. The surface echo is clearly evident as higher intensity at twice the water depth below the surface, and determines the maximum distance the waveform can be analyzed. Figure 29 shows example individual waveforms from the 200 and 24 *kHz* signals for single pings in 8.5 and 2.7 *m* water depths. The substrate in 8.5 *m* depth is much more sandy than that in 2.7 *m* depths where the bottom sediments are predominantly muddy (and may contain vegetation). The effects of volume scattering in the 24 *kHz* signal is clearly evident, especially in the softer muds of the 2.7 *m* depth ping where waveform intensity varies significantly as the pulse reflects from various sediment layers within the seabed. The complexity in the backscattered signal makes analysis difficult for any given ping, highlighting the need to represent the variability of the whole waveform in the principal component analysis.

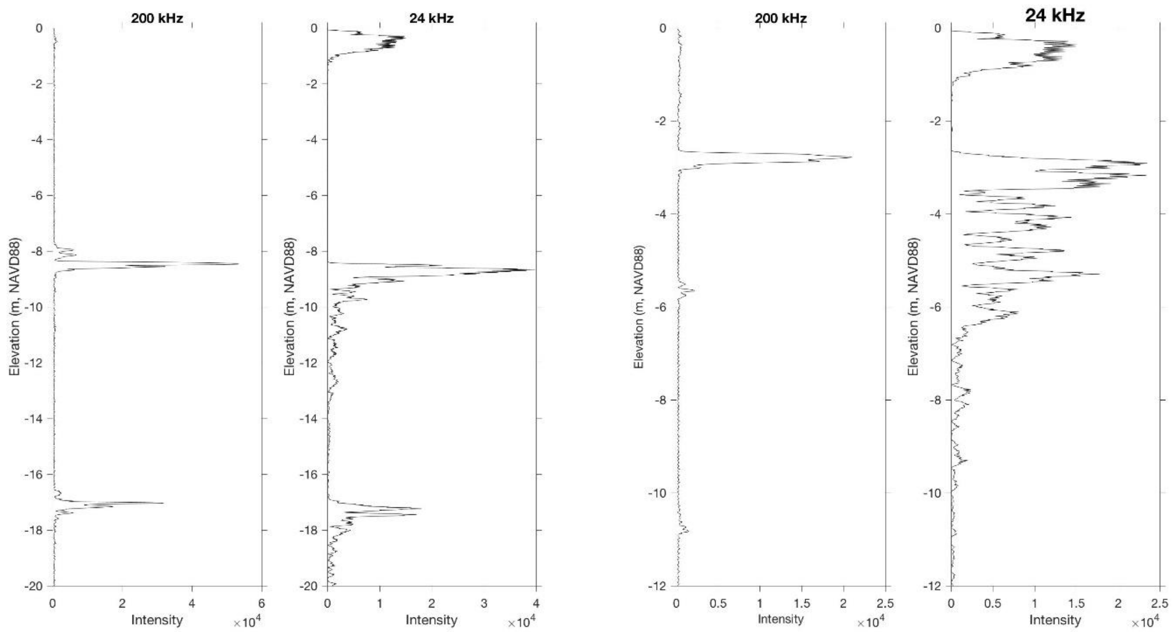


Figure 29. Example waveforms from a single ping from the 200 and 24 *kHz* pulses in 8.5 *m* water depth with mostly sand in the substrate (left panels) and 2.7 *m* water depth with mostly muds in the substrate (right panels). The affects of bottom scattering can be clearly seen in the 24 *kHz* signal, especially in the muddy sediments (right panel), as well as the second surface echo at a depth twice that of the first return.

To analyze the 24 *kHz* data with principal components the mean intensity profile over all pings (Figure 30) must first be removed from the data set. To compute the mean over the whole data set, we first normalized each ping by the maximum intensity along the profile making the range of each ping from 0 to 1. This removes the variation in maximum intensity from the analysis. We also computed the analysis with un-normalized waveforms and found very similar results, and thus proceed in our analysis with the normalized data. To remove some of the fine-scale (sub meter) horizontal variability in the seabed, we smoothed the data by block-averaging over 40 consecutive pings (about 2.5 *s*). This reduced the number of pings over the whole data set by a factor of 40 and allowed the whole data set to be included in the principal component analysis, an important consideration for the maximum (16 GB) memory available on our processing computer system.

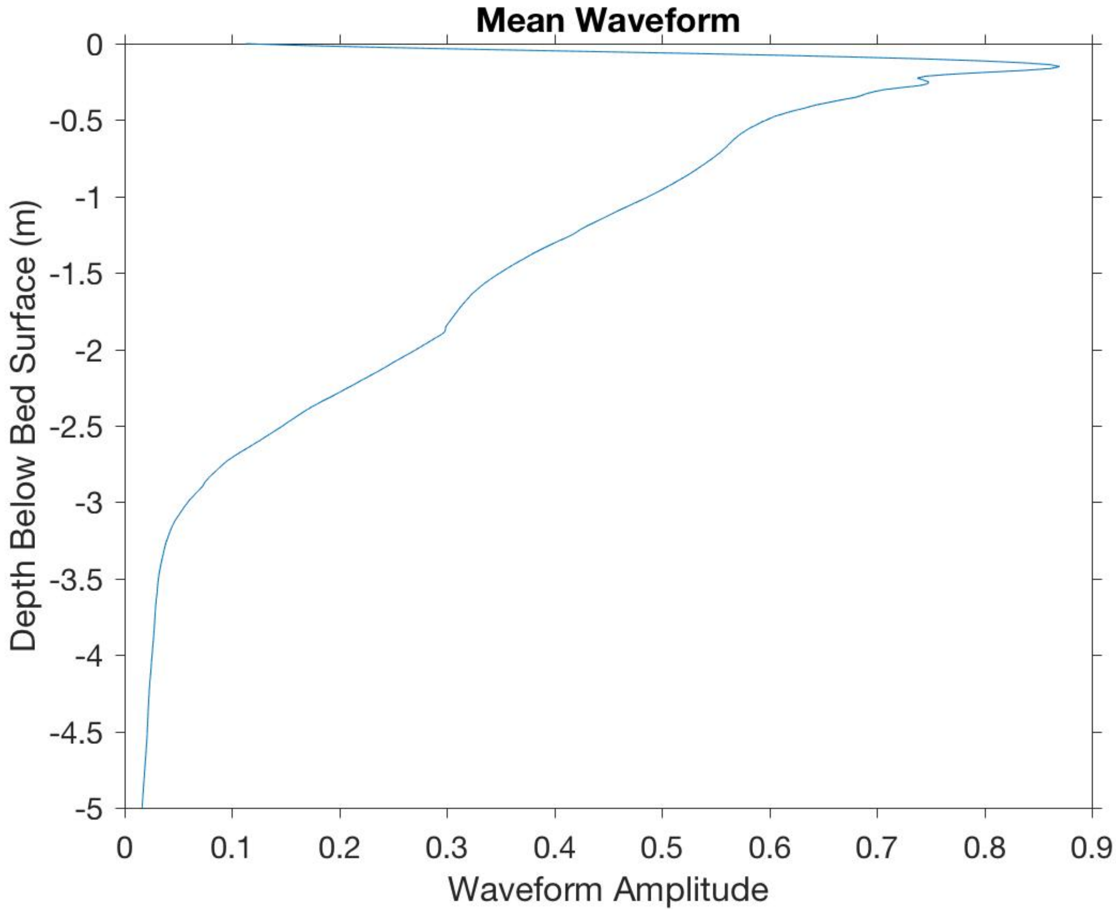
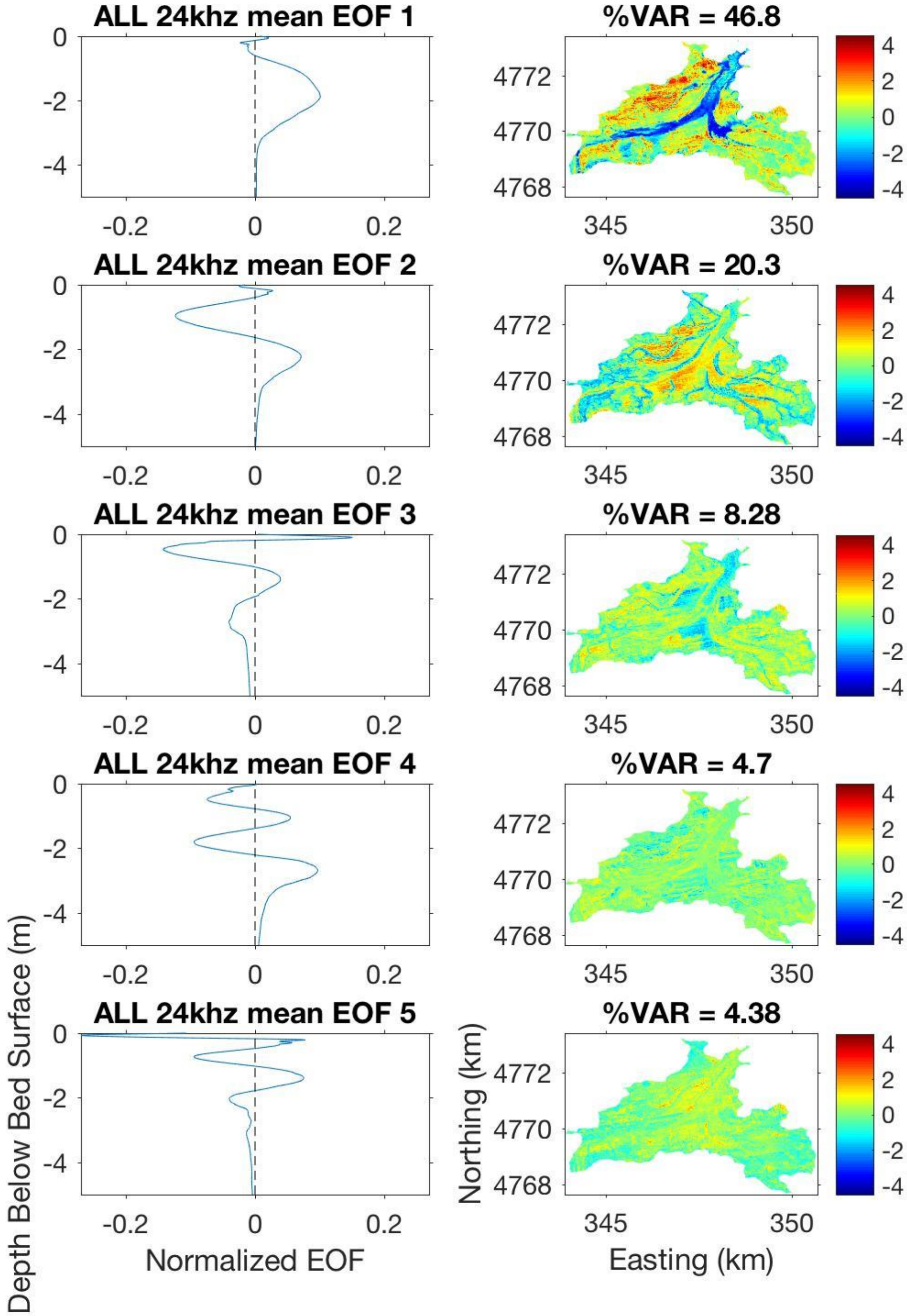


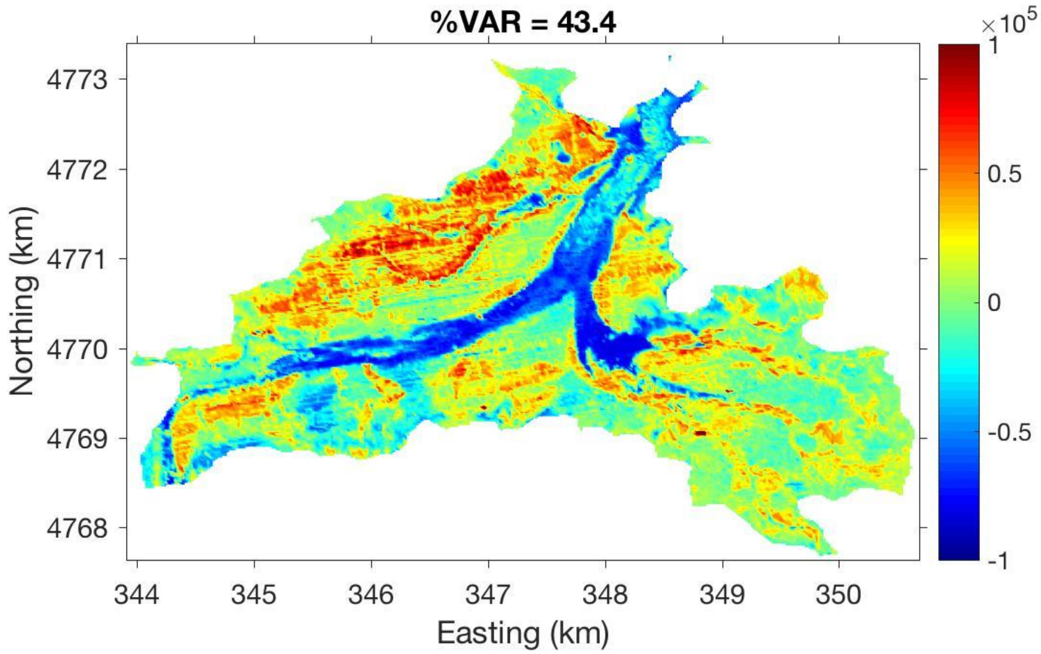
Figure 30. Average waveform from the 24 kHz acoustic pulse with each pulse normalized by the maximum value.

The result from the principal component analysis is shown in Figure 31 for the first 5 EOFs that spanned collectively 84.5% of the variance. Modes 1-5 accounted for 43.8%, 20.3%, 8.3%, 4.7%, and 4.4% of the variance, respectively. The similarity in the variance for modes 4 and 5 suggest that the analysis has reached the “noise” level where it is unlikely that physical meaning can be assigned to those spatial weighting patterns. The spatial variation in the first and second mode (presented with higher resolution in Figure 32) show coherent patterns that do not appear random. These patterns clearly show the location of the tidal channels throughout the estuary, as well as regions with eel grass meadows and mud flats.



ALL 24khz mean EOF 1
%VAR = 46.8
ALL 24khz mean EOF 2
%VAR = 20.3
ALL 24khz mean EOF 3
%VAR = 8.28
ALL 24khz mean EOF 4
%VAR = 4.7
ALL 24khz mean EOF 5
%VAR = 4.38
Depth Below Bed Surface (m)
Normalized EOF
Northing (km)
Easting (km)

Figure 31. First 5 EOFs with the highest variance using the 24 *kHz* signal normalized by the maximum value in each ping and corrected for the mean waveform (shown in Figure 30). The left panels are eigenvectors showing the deviation from the mean waveform for each EOF. The right-hand panels show the spatial variation of the EOF and the variance explained.



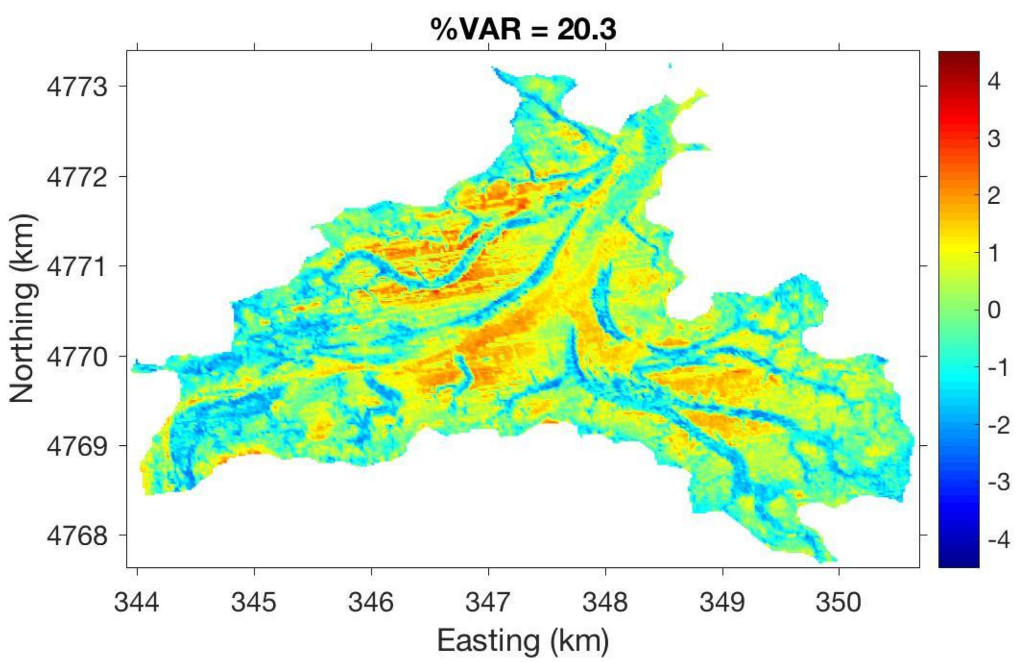


Figure 32. Higher resolution view of the spatial weighting for EOF 1 (upper) and EOF 2 (lower), accounting for 43.4% and 20.4% of the variance, respectively. The spatial patterns have coherent structures that may identify different seafloor characteristics such as the mud flats, tidal channels, eel grass meadows, and other areas such as (potentially) oyster reef habitat.

Mean and Maximum Intensity Backscatter within Substrate Layers

We also computed maximum and average (mean) backscatter intensity maps at 25 *cm* intervals spanning 5 *m* range beneath the seafloor using the 24 *kHz* sonar signal. These maps show the depth variation in backscatter revealing sub-bottom patterns. Backscatter from the top 25 *cm* and from 1.00-1.25 *m* below the seabed has spatial variability that is quite similar to the first two principal components found from EOF decomposition of the entire waveform profiles of the 24 *kHz* signal. This suggests that the EOF decomposition that considers the full waveform has variability strongly reflected in the backscatter properties of substrate near the surface and about 1 *m* below the seafloor. In the main channels, high backscatter from surficial sediments (which are coarser owing to winnowing of fine sediments by strong tidal flows) masks the subsurface structure. However, over the tidal flats with surficial muds the deeper layers reveal a coherent pattern of strong backscatter about 1 *m* into the substrate that appear to be paleo channels cutting across the mudflats and eelgrass meadows, or accumulations of high backscatter material near the sides of the present tidal channels. These high backscatter regions within 1 *m* of the surface could be regions with oyster shell but would require deep (> 2 *m*) cores in strategic locations to reveal the nature of the backscatter.

We examined the depth variation in average and maximum backscatter intensities in 25 *cm* increments extending from the seafloor to 5 *m* depth below the sediment-water interface. These maps allow for evaluation of the spatial patterns that result from subsurface backscatter that reveal coherent sub-bottom patterns that span the estuary. Selected maps for mean depths of 0.125 *m* to 3.125 *m* in 25 *cm* bins at 1 *m* increments are shown in Figure 8 for the maximum intensity backscatter and in Figure 9 from the average (or mean) intensity.

In general, the maximum and average intensity show very similar patterns. In particular, the most shallow backscatter (interrogating the near surface sediment layers) reveal strong backscatter in regions associated with coarser surficial sediments most notably in the deeper tidal channels where strong tidal currents winnow the fine materials leaving behind coarser grains that are not entrained in the flow. At about 1 *m* below the surface, the backscatter patterns reveal a coherent pattern of strong backscatter that appear to be associated with paleo tidal channels that cut across the mudflats and eel grass meadows. It should be noted that the weaker backscatter in the present tidal channels is likely masked by the strong acoustic reflection of coarser surface material (revealed in the shallower backscatter map). Interestingly, the backscatter map at about 2 *m* depth indicates a strong acoustic backscatter layer in the northwest part of the estuary. The nature of this backscatter is unknown, and would require deep coring (> 2 *m*) to examine the contents of the substrate. The deeper backscatter maps have much less spatial extent across the estuary induced by water depth variations that limit the useable backscatter that is not affected by secondary reflections from the surface (that is, the time of detection is limited by multiple reflections of the sound pulses between the surface and the bottom that depends on the water depth).

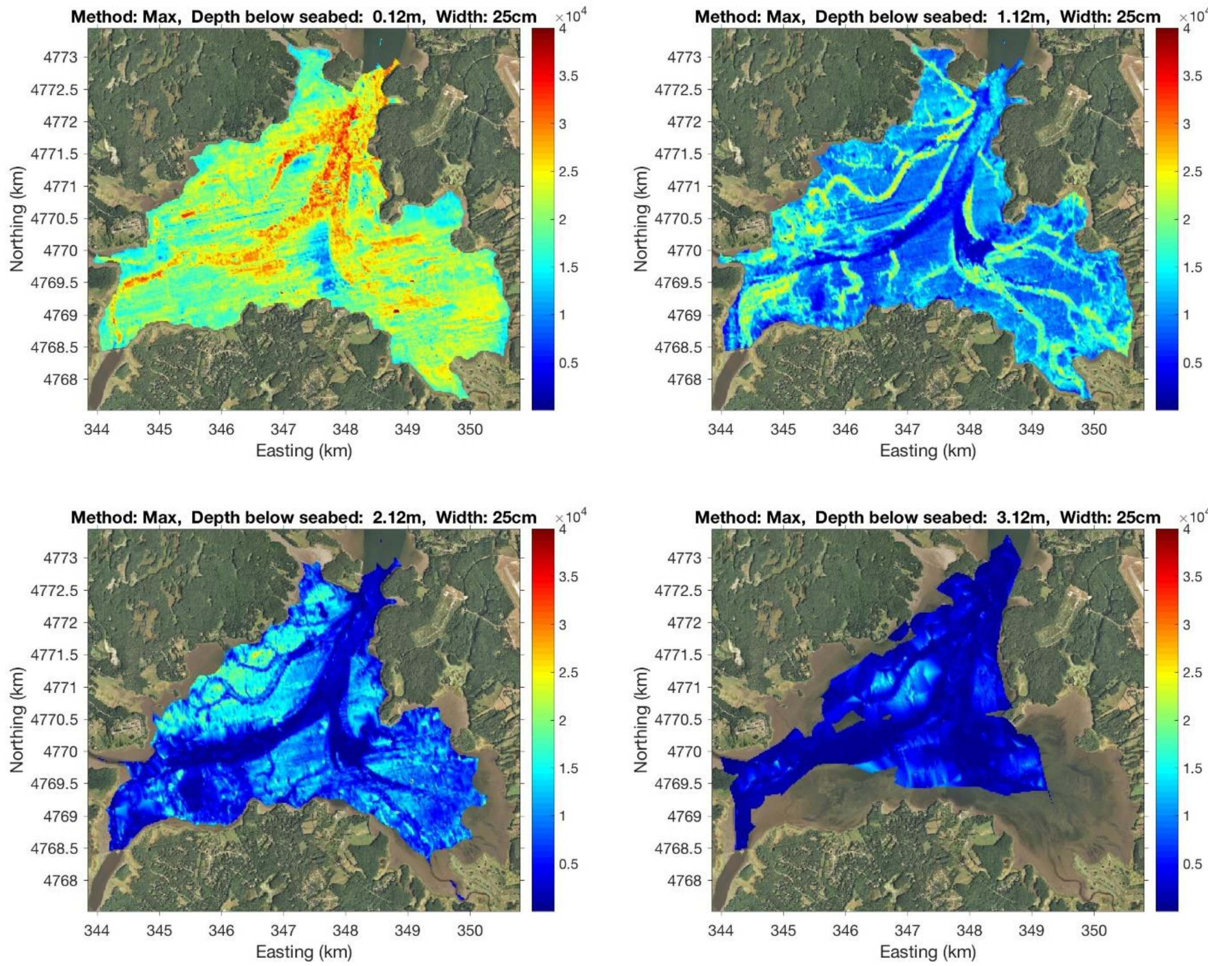


Figure 33. Maximum intensity over a 25 *cm* bin at depths below the sediment-water interface ranging (top left) 0-0.25 *m*, (top right) 1.00-1.25 *m*, (bottom left) 2.00-2.25 *m*, and (bottom right) 3.00-3.25 *m*. Horizontal coordinates are UTM Eastings and Northings (in *km*).

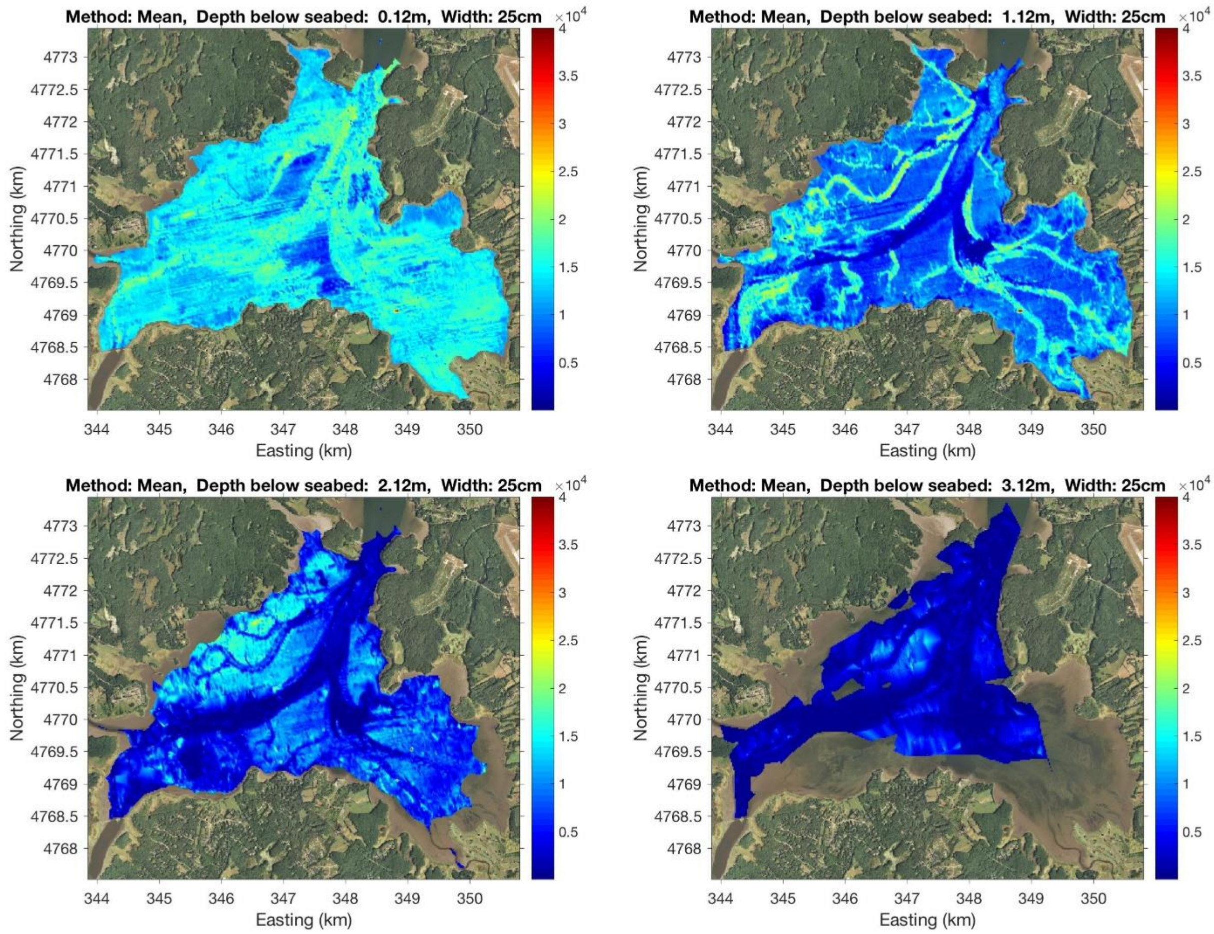


Figure 34. Average (mean) intensity over a 25 *cm* bin at depths below the sediment-water interface ranging (top left) 0-0.25 *m*, (top right) 1.00-1.25 *m*, (bottom left) 2.00-2.25 *m*, and (bottom right) 3.00-3.25 *m*. Horizontal coordinates are UTM Eastings and Northings (in *km*).

The backscatter maps shown in Figures 33 and 34 can be compared with the EOF's produced from the eigenvector decomposition discussed in the previous report. Figure 35 shows a comparison of the first 2 EOF modes (accounting for 43.4% and 20.3% of the variance associated with the full waveform analysis) with the maximum backscatter intensity maps at depth ranges of 0-0.25 *m* and 1.00-1.25 *m*. The spatial patterns of the first EOF and the shallow maximum backscatter map are qualitatively similar, as is the comparison between the second EOF and the deeper (1 *m*) backscatter map. This suggests that the EOF decomposition of the full waveform data is reflecting the variation in backscatter as a function of depth, and capturing the layering of sedimentary material below the surface. The consistency between these maps also shows that the EOF decomposition is not strongly affected by the orthogonality constraints in the EOF decomposition of the data, at least for the first 2 EOF modes that combined account for 63.7% of the variance.

These maps can guide future efforts to ground truth the backscatter data. In particular, the collection of deep vibra-cores that extend through the substrate up to 3 *m* in depth are needed to identify the nature of the backscatter. Presently, USDA has been collecting deep vibracores in the estuary for the past 2 years, with additional sampling expected in the next couple of years. Collaborations with the USDA are underway, and it is hoped that cores can be obtained in specific areas to better assess the nature of the sub-bottom backscatter in terms of oyster reef history in the estuary.

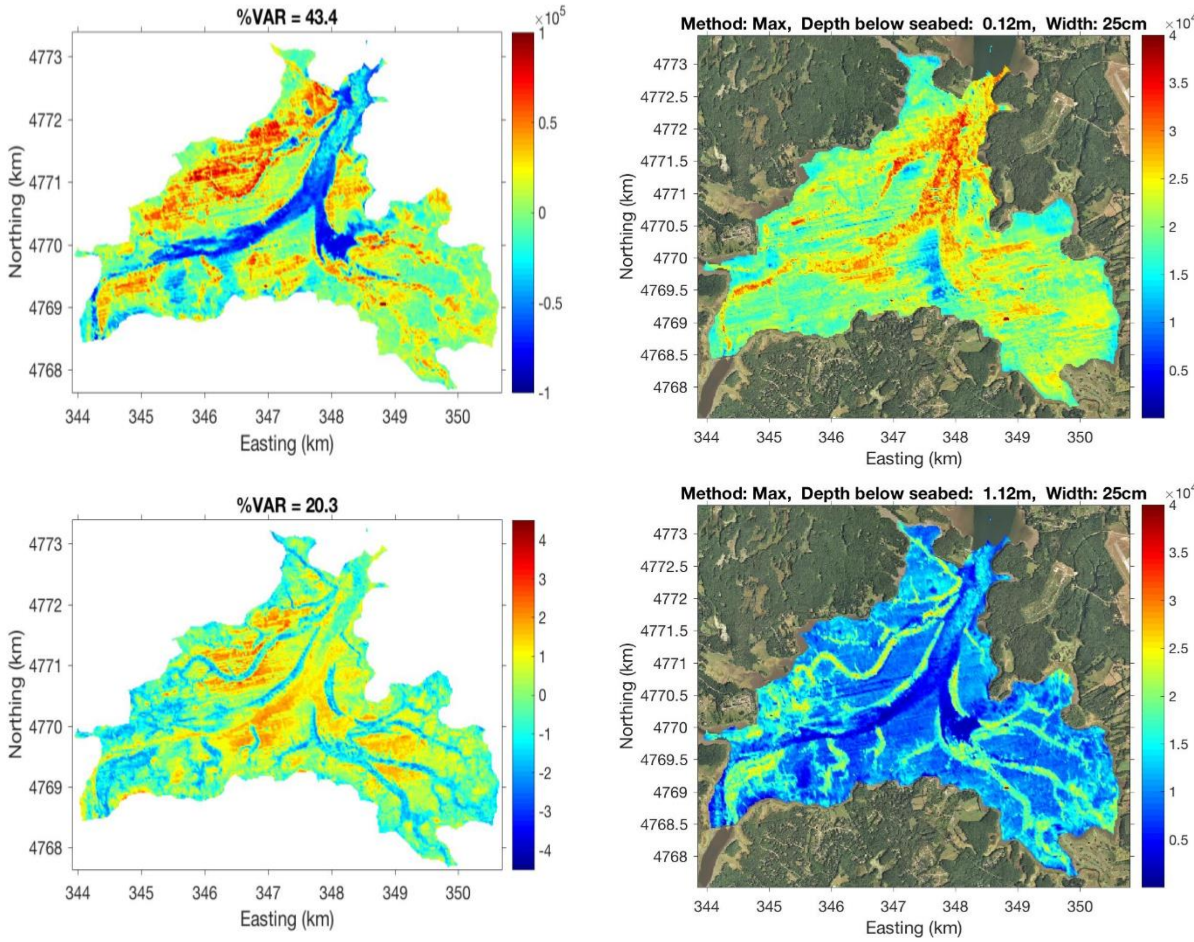


Figure 35. Comparison of the spatial weighting for EOF 1 (top left) and EOF 2 (lower right), accounting for 43.4% and 20.4% of the variance, respectively, with the maximum backscatter at depth range 0-0.25 *m* (top right) and 1.00-1.25 *m* (bottom right). Although the cover scheme is inverted between the EOF's and the maximum backscatter maps (a result simply of the sign changes in the EOF's), the spatial patterns are quite similar.

<u>Deliverables</u>

Deliverables for this work include all data sets obtained and utilized in the research. This includes all processed multibeam bathymetry data (including surveys at restoration sites and natural reefs), contour lines of identified mounds in the various restoration sites, and mound locations. Also included are time series of the depth-averaged ADCP current data and water levels obtained at Nannie Island in 2018. Processed acoustic backscatter data (EOF results and maximum mean intensity) were also included.